

*NASA-CR-196596*

**AMCC CASTING DEVELOPMENT  
FINAL REPORT**

NASA Contract No. NAS8-39027

Data Requirement #DR-06

**Volume II - Final Report**

Nasa Dwg. #96M66441 / PCC P/N 20013

March 29th, 1995

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NASA Contract No. NAS8-39027

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**Volume I - Executive Summary**

Nasa Dwg. #96M66441 / PCC P/N 20013

March 28th, 1995

3/29/95

## AMCC CASTING DEVELOPMENT FINAL REPORT

### **Data Requirement Overview (NASA contract no. NAS8-39027):**

DR-01 Technical Implementation Plan: See pages 1 thru 11 & 24 thru 39 of 'Technical Proposal - NASA AMCC Volume 1' dated 9/12/91.

DR-02 Logic Network and Key Milestone Charts: See pages 19, 20, 22 & 23 of 'Technical Proposal - NASA AMCC Volume 1', dated 9/12/91, and updates included in the Preliminary Design Reviews dated 8/26/92 & 10/12/93.

DR-03 Casting Hardware Acceptance Test and Inspection Plan: See pages 12 thru 18 & 21 of 'Technical Proposal - NASA AMCC Volume 1', dated 9/12/91, and updates included in the Preliminary Design Reviews dated 8/26/92, 10/12/93 & 9/21/94.

DR-04 Detailed Design Review: See the 'Preliminary Design Review' dated 9/21/94.

DR-05 Final Review: Deleted due to Program Cancellation.

DR-06 Final Report: See the table of contents on page 3.

DR-07 Casting Specification: See the table of contents on page 3.

DR-08 Quarterly Reports: See the table of contents on page 3.

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## **AMCC CASTING DEVELOPMENT FINAL REPORT - EXECUTIVE SUMMARY**

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# AMCC CASTING DEVELOPMENT FINAL REPORT

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- 1) Executive Summary
- 2) Technical Proposal dated 9/12/91
- 3) Preliminary Design Review dated 8/26/92
- 4) Preliminary Design Review dated 10/12/93
- 5) Preliminary Design Review dated 9/21/94
- 6) DR-07 Casting Specification
- 7) DR-08 Quarterly Reports

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# AMCC CASTING DEVELOPMENT FINAL REPORT - EXECUTIVE SUMMARY

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- 2) Results & Conclusions
- 3) Design Recommendations

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## **AMCC CASTING DEVELOPMENT FINAL REPORT - EXECUTIVE SUMMARY**

### **Significant Achievements & Activities:**

PCC successfully cast and performed non-destructive testing , FPI & X-ray, on seventeen AMCC castings (NASA dwg. #96M66441 / PCC P/N 20013). Destructive testing, lab analysis & chemical milling, was performed on eleven of the castings and the remaining six castings were shipped to NASA or Aerojet. Two of the six castings shipped , lots 015 and 016, were fully processed per blueprint requirements. PCC has fully developed the gating and processing parameters of this part and feels the part could be implemented into production, after four more castings have been completed to ensure the repeatability of the process.

The AMCC casting has been a technically challenging part due to its size, configuration and alloy type. The height and weight of the wax pattern assembly necessitated the development of a hollow gating system to ensure structural integrity of the shell throughout the investment process. The complexity in the jacket area of the casting required the development of an innovative casting technology that PCC has termed 'TGC' or Thermal Gradient Control. This method, of setting up thermal gradients in the casting during solidification, represents a significant process improvement for PCC and has been successfully implemented on other programs. The alloy, JBK-75, is a relatively new alloy in the investment casting arena and required our engineering staff to learn the gating, processing and dimensional characteristics of the material.

## AMCC CASTING DEVELOPMENT FINAL REPORT - EXECUTIVE SUMMARY

### Results:

Metallurgical integrity of the final four castings was very good. Only the areas of the parts that utilized 'TGC Shape & Location System #2' (see 'Preliminary Design Review' dated 9/21/94 - included in Volume II - Final Report) showed any significant areas of microshrinkage when evaluated by Non-Destructive Tests (FPI & X-ray). Alumina Oxides detected by FPI on the 'float' surfaces (top side surfaces of the casting during solidification) of the part were almost entirely less than the acceptance criteria of .032" in diameter. Destructive chem mill of the castings was required to determine the effect of the process variables used during the processing of these last four parts (with the exception of the 'Shape & Location of TGC' variable). The worst area of microshrinkage, detected by lab analysis of non-chem milled sections of the final four castings, was 4.5% shrinkage in a heavy cross-sectional area of the part (see lab results in 'Preliminary Design Review' dated 9/21/94 - included with Volume II - Final Report). Maximum observed IGA/IGO, in these same four parts, was .001" and only localized pooling of eta phase was detected in the heavy cross-sectional areas (see lab results in 'Preliminary Design Review' dated 9/21/94 - included with Volume II - Final Report). Maximum columnar grain detected is 1.3" and the maximum equiaxed grain detected is 0.9" (see lab results in 'Preliminary Design Review' dated 9/21/94 - included with Volume II - Final Report).

Dimensional conformance of the final four castings was very good. The only significant dimensional characteristics with a Cpk less than '1.0' are the jacket profile from datums and the mis-match requirement of the manifold patches (see dimensional review in 'Preliminary Design Review' dated 9/21/94 - included with Volume II - Final Report).

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## AMCC CASTING DEVELOPMENT FINAL REPORT - EXECUTIVE SUMMARY

### **Conclusions:**

The gating & processing parameters, when utilizing TGC 'Shape & Location system #1' (see Preliminary Design Review dated 9/21/94 - included with Volume II - Final Report), appears to be ready for production, but will require the processing of an additional four castings to ensure the repeatability of the process.

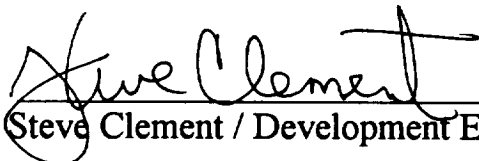
The dimensional conformance of the part appears to be ready for production with the exceptions of the jacket profile from datums & the mismatch requirement of the manifold patches (see Design Recommendations on pg. 7 & see dimensional review in 'Preliminary Design Review' dated 9/21/94 - included with Volume II - Final Report).

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## AMCC CASTING DEVELOPMENT FINAL REPORT - EXECUTIVE SUMMARY

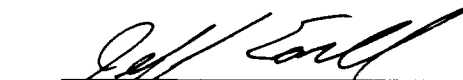
### Design Recommendations:

PCC has determined that the AMCC casting (NASA dwg. #96M66441 / PCC P/N 20013) is fully castable in its current form. PCC strongly recommends that all castings produced from JBK-75 be designed, as this part was, with an FPI non-interpretable level of .032" in diameter. PCC recommends construction of a one piece tool, to form the jacket area of the casting, to enable PCC to meet the jacket profile from datums criteria. The other alternative to this would be relaxation of the criteria on the blueprint. The mis-match requirement for the manifold patches as currently called out on the drawing is not within the process capability of this casting. PCC recommends that NASA & PCC concurrently engineer a resolution to this dimensional non-conformance.

  
Steve Clement / Development Engr.

  
Pam Wright / Dimensional Engr.

  
Joe Franich / Quality Engineer

  
Jeff Earll / Program Manager

TECHNICAL PROPOSAL  
NASA AMCC  
VOLUME 1

Revised 8/19/91  
9/12/91



## TECHNICAL PROPOSAL VOLUME 1, PART 1:

Precision Castparts Corporation (PCC) Large Structural Business Operation (LSBO) proposes to produce twenty-one (21) castings for the NASA AMCC program, of which nine (9) will be deliverable per NASA blueprint number 96M66441. A signed, released copy of this drawing will be required prior to beginning of the program. This effort will be designed to yield a one piece casting, with a 2 or 3 piece approach as a backup in case the one piece casting is not feasible.

PCC feels that the one piece casting configuration carries a minimum of risk since NASA has chosen to eliminate the cored holes from the Fore and Aft Manifolds. The casting development program, therefore, will be designed to concentrate on the metallurgical and dimensional requirements of the part, which at this time are thought to be achievable.

The pattern tooling that will be built to produce this casting will be capable of producing it in any combination of one, two, or three pieces. The development program as quoted in this proposal will, however, refer only to the single piece approach. If, by mutual agreement, this is later abandoned, the backup approach will then be negotiated.

The casting design as shown on the blueprint is assumed by PCC to be acceptable to NASA. During the course of the development program, PCC may make suggestions concerning the design. These will be for producibility requirements only, and will not be incorporated without NASA agreement. The functional requirements of the part in its end use in the engine are NASA's responsibility and PCC assumes no liability for these once the acceptance standards for the casting have been met.

The use of JBK-75 alloy is assumed in this proposal. Its use at PCC LSBO has been limited, with no parts as yet having reached a production status. However, it has been found to be very castable and weldable, with good response to HIP. Information concerning its processing in our facility, which is obtained from current programs, will be used in this program as it is applicable.





The use of other alloys will require a re-evaluation and restructuring of this program. NASA 23 is unknown to us at this time and would require initial evaluation prior to running the program. Inconel 718 has wide usage and represents a large percentage of PCC LSBO production. We would consider it a good alloy for this casting, however, NASA must determine its suitability for this application.

E

The initial part of this program is designed to develop a gating system and processing parameters that will produce sound castings, i.e. those that will meet the Metallurgical and Dimensional requirements for the part. As such, the first 12 castings produced will be destructively tested, and thus will not be available to ship to NASA in usable form. All will not be completely processed, and the leftover pieces will be various configurations, heat treat conditions, and surface conditions. These would be available to NASA after PCC's evaluation is complete. Data packages on these casting segments would not be available except on an informal basis. These segments should not be used by NASA in any way to evaluate the characteristics of cast parts, as by their nature they do not represent the final product.

E

The development process as quoted will be made up of the following steps.

- 1) Receipt of Purchase Order
- 2) Tool Procurement, Construction and Proving
- 3) Process #1 Mockup Casting
- 4) Process #2 Mockup Casting
- 5) Detailed Design Review
- 6) Gating Optimizations - Process 4 Castings (DOE)
- 7) Deliver 3 Hipped Parts
- 8) Detailed Design Review
- 9) Process Optimization - 6 Castings (DOE)
- 10) Detailed Design Review
- 11) Produce Six Castings from fixed process

This process may require additional steps in order to obtain the desired results. The decision to proceed or to repeat prior steps will be mutually agreed upon at the Detailed Design Reviews. Changes to work content will be decided at that time.



This effort will be directed by an Engineering Team composed of the following positions:

Program Manager	1280	hours
Project Engineer	736	hours
Dimensional Engineer	2299	hours
Part Engineer	2813	hours
Quality Engineer	2371	hours
Technician	2560	hours
Clerk	1048	hours

The hours shown are the estimated hours that will be required by each person in order to complete the project.

Ref. Attachments pages 4 & 5.

PCC has certain materials and processes which are considered to be proprietary. Prior to acceptance of a purchase order, a non-disclosure agreement must be agreed upon between NASA and PCC. The items to be named are included but not limited to the following list:

Wax Formula  
Shell Formula  
Gating Information  
Pouring Temperature  
Shell Temperature  
Welding Techniques  
CMM Programs  
Wax Assembly Techniques  
Shell Building and Preparation Techniques  
Shell and Gating Removal Techniques  
Volumetric Shrink Data  
Part Routers (Shop Travelers) and other internal documentation.

# ENGINEERING HOURS BY TASK, BY ENGINEER, BY CALENDAR YEAR

1991

	JD	JM	BH	PW	Clk.	JH	SW
Tooling	160	40	24	32	24	48	48
Sample 1 & 2	120	146	56	92	40	40	32
Gating DOE							

Qualification }  
& }  
Test Piece(s) }

Tooling & Best  
Effort Casting 10

Travel	96	96	96	96	0	0	96
Reporting	50	80	80	50	90	36	42
	426	362	256	270	154	124	218

1810 Hours

## TOTAL MANHOURS BY PERSON

JD	2299
JM	2813
BH	2371
PW	2560
Clk.	1048
JH	736
SW	1280
<b>Total Proposal</b>	<b>13,107</b>

1992

	JD	JM	BH	PW	Clk	JH	SW
	360	438	168	276	120	112	96
	64	96	64	128	30	16	12

Travel	96	96	96	96	0	0	96
Reporting	50	80	80	50	90	36	42
	570	710	408	550	240	164	246

2888 Hours

# ENGINEERING HOURS BY TASK, BY ENGINEER, BY CALENDAR YEAR

1993

1994

	JD	JM	BH	PW	Clk.	JH	SW	JD	JM	BH	PW	Clk.	JH	SW
Tooling														
Sample 1 & 2														
Gating DOE	192	288	192	384	90	48	36							
Qualification & Test Piece(s)	256	256	600	360	120	152	240							
Tooling & Best Effort Casting 10								563	845	563	704	264	176	264
Travel	96	96	96	96	0	0	96	96	96	96	96	0	0	96
Reporting	50	80	80	50	90	36	42	50	80	80	50	90	36	42
	594	720	968	890	300	236	414	709	1021	739	850	354	212	402
	4122 Hours							4287 Hours						



## **TECHNICAL PROPOSAL VOLUME 1, PART 2:**

### **TECHNICAL IMPLEMENTATION PLAN**

Precision Castparts Corporation has refined the art of investment casting into a process capable of accurately reproducing part designs in many high strength environmental resistant alloys.

Investment casting, "the lost wax process", involves the creation of wax injection tooling capable of producing highly repeatable patterns. During the process of making ceramic molds in which to pour liquid metal, these patterns are destroyed, and hence the name, "lost wax process". The techniques for pouring metal are carefully developed for each part design. After the ceramic mold material is removed, the castings are subjected to x-ray radiography, fluorescent dye penetrant, and visual inspections to provide assurance of the casting quality. When necessary, PCC is able, through in-process welding, to fabricate or replace areas of the casting, using welding techniques developed specifically for the particular casting shape and alloy. Stringent controls are maintained to assure quality and timely deliveries. These include metal testing, thermal monitoring, dimensional inspections, manufacturing instruction controls, and employee certifications.

The following is a technical summary, showing the application of investment casting to the NASA objective of a "one-piece" Advanced Main Combustion Chamber in JBK-75 alloy. This single casting will integrate the Forward Coolant Manifold, Structural Jacket, and Aft Coolant Manifold.

Tooling, gating, and casting parameters are unique to the shape of the design and the alloy of choice. A structured development plan, utilizing an iterative process of experimentation, will be employed to define a process which is capable of meeting the quality expectations of NASA.

Initial process parameters will be set by experience. Since the requirements referenced in this request for proposal are non-traditional for our experience regarding section thickness and alloys, only the most basic assumptions can be made from direct experience and recent research. Therefore PCC proposes to



utilize a development effort that is typically applied to products made for a new market segment.

Destructive evaluation methods (i.e. chemical milling and sectioning) will be employed on the first twelve (12) castings produced. This approach supports the expedited development necessary for PCC to reach an acceptable quality level for the nine (9) deliverable castings. The three castings provided for manufacturing development will not be subject to quality acceptance requirements beyond those identified and agreed to by PCC prior to their manufacture. Prior to flight hardware production of this casting, additional process development may be required.

A change in the selection of JBK-75 alloy, if made after the start of casting development, will result in the need to repeat portions of the development effort and could require the rework of pattern tooling to achieve dimensional expectations. Were this decision to be made, PCC retains the option to renegotiate the cost and schedule of this proposal.

A development team containing expertise in program management, metallurgy, process design, dimensional control and quality assurance has been assembled to implement this plan.

## **TYPICAL DEVELOPMENT PROCESS**

Included as a reference is an attachment page which describes a typical development process for an aircraft engine frame (pages 19 & 20).

## **PROPRIETARY INFORMATION**

Techniques, fixtures (except those identified in this proposal), processes, in-process data, or relationships which are utilized or evaluated during this stage of development, developed by PCC, are considered proprietary and competition sensitive as discussed elsewhere in this proposal. All data relating to the final condition of completed castings will be made available to NASA at the times indicated in the proposal milestone chart.

E



## **PROPOSAL DEVELOPMENT PLAN**

As discussed elsewhere, the goal of this proposal is to develop the AMCC casting through the process DOE activity and to deliver, to NASA, six (6) castings that are developed to the highest quality possible under the SOW and delivery schedule provided by this request for proposal. The following is a concise description of the tasks shown on the proposed milestone for this effort.

### **High Quality Segmented Tooling:**

#### **A. Wax Injection Dies.**

Injection tooling, as designed and purchased, will be capable of producing the Main Combustion Chamber pattern as well as individual patterns for the Forward Manifold, Aft Manifold and Structural Jacket. This will allow for the implementation of "two or three piece" solutions if unforeseen problems are experienced with the "one piece" effort.

#### **B. Fixturing.**

Fixtures that are required in the manufacturing process will be designed and purchased. Included in this proposal are fixtures unique to this program.

1. Wax Holding -- to prevent distortion
2. Pattern Assembly -- to locate features
3. Gating Assembly -- to prevent distortion
4. Casting Manipulators -- for gate removal/welding/inspection
5. Gauges and templates -- for inspection/welding
6. Holding Fixtures -- for target machining/measuring

### **Mockup Casting Development - The Objective of these Trials are to:**

#### **A. Evaluate manufacturing techniques and develop prototype fixtures for:**

1. Wax Injection Molding:  
This includes definition of set-up parameter, operational performance and handling methods for all wax injection dies including: pattern, chill soluble, wax welded and gating components.
2. Pattern Assembly
3. Gate Assembly



4. Ceramic Mold Making: (Investing Process)  
Investing is the process in which ceramic mold materials are applied to the wax pattern. This provides a vessel for alloy pouring which reproduces with exacting detail the wax pattern/gate assembly.
5. Melting and Pouring of the Alloy: (Casting Process)
6. In-process Welding of the Casting
7. In-process Inspections

B. Collect data to establish part/alloy volumetric shrinkage.  
This is accomplished by: Physical measurement of select areas of the tooling, wax pattern, pattern/gating assemblies, metal part (as cast, hot isostatic pressed and solutioned, and aged conditions) and comparison to blueprint and target values. This allows us to accurately predict the size of the part resulting from our process and provides direction for improvement efforts, and to establish actual dimensions for future production tooling.

C. Evaluate several gating ideas.

Mockup gating systems will be applied which provide for an understanding of the effects of gating in promoting the metallurgical quality of this casting.

D. Experience casting JBK-75

E. Programming of coordinate measuring machine  
CMM for inspection of both wax patterns and castings

F. Design and construct fixtures as needed

G. Obtain in-process welding experience

H. Establish inspection techniques

I. Determine JBK-75 behavior (HIP, IGA, melting , properties)





### **Gating Design of Experiments (DOE)**

The objective of these castings is to allow statistical comparison of the gating options resulting from the mockup castings. Upon completion, PCC shall select a system for the six (6) process DOE castings. Using four (4) castings PCC shall attempt to achieve improved metallurgical quality through gating refinement.

Statistically designed experimentation will be conducted to evaluate the effect of changes to the gating system on metallurgical quality. These experiments will be available for review by NASA prior to manufacture of the castings.

Destructive methods (chemical milling) will be performed on four (4) castings for evaluation of internal quality and as a review of the effectiveness of the inspection procedures. The results from all four castings will be provided as a package at the completion date shown on the proposal milestone. This will include non-destructive inspection (fluorescent penetrant and x-ray) reports, final dimensional inspection results (including any data collected by Coordinate Measuring Machine), and reports of the metallurgical character of excised defect indications. Thermal processing records and metal chemistry results (PCC does not plan to certify results from development castings) may be provided upon request. Due to the nature of experimentation, it is unlikely that any one casting will have superior quality throughout. Rather each casting is likely to experience a range of casting quality in different areas.

### **Tooling Modifications**

Modification of pattern tooling may be required to provide suitable size characteristics for deliverable castings. PCC will, as required, rework tooling to provide dimensional improvements needed for the deliverable castings. The cost of this effort is included in the financial section of this proposal.

### **Gating Die/Fixture Construction**

To provide for consistent quality of the deliverable castings, wax injection tooling will be constructed to provide as many of the gating components as



possible within the time requirements of this request for proposal. This typically would include risers, cups, runners and ring gates as well as the associated chill waxes. The design and construction of fixtures (as noted elsewhere) shall be completed during this phase of the development effort.

## **PROCESS OPTIMIZATION (DOE)**

Process will manufacture six (6) castings, all using the best gating system from the gating experiment. The process parameters for these castings (metal temperature, mold temperature, amount of ceramic material) will be varied to determine the sensitivity of casting metallurgical and dimensional quality. The castings will be evaluated using the same techniques that were identified previously for the gating experiment. Information from these castings will provide a statistical basis for measuring the effect of three process parameters and for determining mutually agreeable acceptance criteria for castings.

Dimensional data collection.

PCC will review the blueprint for specific control dimensions, with the intent of collecting data which can be used to provide a statistical description (mean and standard deviation) of the casting process. This data will provide an indication of the dimensional results that can be expected for the deliverable castings.

## **Deliverable Castings**

PCC will run 3 castings in conjunction with the four Gating Optimization parts. These will not have the access windows closed, will be HIPped, will have pre and post HIP NDTE as the schedule allows, and be processed on a best effort basis for metallurgical and dimensional quality. These three parts will ship by the end of June, 1993.

After the six (6) piece process optimization, using the same process for each, PCC will manufacture six (6) castings for delivery to NASA. These castings will be Hot Isostatically Pressed, solution heat treated, in-process welded, fluorescent penetrant, x-ray inspected, and age heat treated to agreed upon acceptance standards. Although the process used on all six parts will be the same, at this stage of development this process is not intended to produce production castings. Additional development is required to refine process parameters before the process can be considered "fixed".



## **TECHNICAL IMPLEMENTATION PLAN DIMENSIONAL DEVELOPMENT**

### **TOOLS: (WAX INJECTION DIES)**

Tooling to be (layout) inspected for dimension conformance to design requirements using surface plates, height gages and/or coordinate measuring equipment.

### **WAX PATTERNS:**

Each wax component to be initially inspected for physical size, wall thickness, feature sizes and location. Subsequent waxes will be checked using control dimensions.

### **WAX PATTERN ASSEMBLY:**

Each pattern assembly consists of three basic components: Forward Manifold, Jacket and Aft Manifold. These components will be located by an assembly fixture that places each wax in its proper location. After wax welding to make the complete assembly, the pattern will be visually and dimensionally inspected for conformance to blueprint. The assembly will be measured by a coordinate measuring machine to assure correct angular positions of each component and to measure contour surfaces that cannot be inspected with precision hand tools.

### **GATED PATTERN ASSEMBLY:**

Each gated assembly will be checked for distortion prior to investing. Any deviations will be recorded for their impact on the casting. Corrections will be made to the assembly as required.



## **CASTING:**

Each configuration will be dimensionally inspected at the stages of process that have an effect on dimensions. The planned inspections are after the following:

- 1st Inspection (as cast)
- Homogenize or HIP Heat Treat
- Solution Heat Treat
- Age Harden Heat Treat
- Target Machining

Inspections are not limited to the above control points and may include additional points as required.

The purpose of the dimensional inspection plan is to characterize the JBK-75 alloy. This includes volumetric shrink (size of pattern required to meet drawing dimensions) process variation (repeatability of dimensions), and unusual volumetric shrink (thick section walls of features may require additional shrinkage allowance)

## **POTENTIAL PROBLEM:**

A possible problem that requires work is the dimensional inspectability of the Forward and Aft Manifold wall thicknesses. The wall cannot be inspected with precision hand tools. (Either calipers or micrometers) The need is to develop alternative methods such as ultrasonic testing to insure wall thickness conformance to blueprint. This includes local blend areas and the wall surfaces around the patch windows. Work to be done includes using sample sections of JBK-75 castings currently in-process and pieces of the NASA casting as standards to calibrate testing units. Data from casting measurements (casting cut ups) will be analyzed by statistical methods to determine reliability.



## **TECHNICAL IMPLEMENTATION PLAN**

### **OTHER ENGINEERING EFFORTS:**

PCC will work with and support the contracting agency in the development of appropriate standards and specifications in order to meet their needs and requirements. At the completion of the development program, viable specifications and standards, suitable for casting production, will be available.

PCC will be running similar parts in JBK-75 at the same time that this program is active. We will transfer the knowledge gained in those efforts to this one as it is applicable.



## TECHNICAL IMPLEMENTATION PLAN

### INSPECTION PLAN:

A detailed inspection plan will be designed for each significant process in the casting development program utilizing, at a minimum, the inspection methods defined below.

For each level of inspection, and by each of the inspection methods defined, the process will be controlled by internal inspection documents referred to as technique cards and process control procedures.

Inspection processes identified as significant to the proposed development program are dimensional and non-destructive testing.

#### 1. Dimensional:

##### A. Wax Pattern, Inspection of.

Required to validate the wax injection tool construction and to provide a dimensional data base for correlation of the wax to metal shrink factor.

##### B. Cast Part Configuration, Inspection of.

Correlates previously acquired wax dimensions with the actual metal dimensions and provides specific dimensional data from which wax tooling adjustments, if determined significant, would be performed.

##### C. In-process Inspection of Development Parts.

Evaluation of the effects of thermal cycling, i.e. Hot Isostatic Pressing and Heat Treat effects on casting configuration and dimensions.

##### D. Final Inspection of Qualification Part.

Evaluation and verification of all the dimensions required by the blueprint.

PCC is well equipped to perform dimensional inspection utilizing a wide variety of manual and automated inspection equipment, from hand held micrometers to fully automated, programmable coordinate measuring machines of sufficient envelope size to accommodate the proposed castings.



PCC intends to fully utilize all the appropriate measurement equipment commensurate to the task of gathering dimensional data and to provide dimensional verification.

## 2. Non-destructive Testing

The non-destructive testing methods used at PCC are:

1. Visual
2. X-Ray
3. Fluorescent Penetrant
4. Magnetic Particle
5. Ultrasonic

### A. Visual Inspection

Each casting will be evaluated for its visual condition relating to surface finish, completeness and condition. This inspection will take place at a minimum of three (3) specific points in the development program.

#### 1. 1st Inspection.

This operation is performed as the first operation after the casting is cleaned.

#### 2. Visual Inspection, in-process.

Performed as needed during the internal manufacturing processing of the casting at any time a process operation might cause a condition that affects visual standards.

#### 3. Final Visual Inspection.

Performed in conjunction with the final dimensional inspection to verify that visual conditions meet specification.

PCC has sufficient and adequate visual inspection equipment, magnifiers, remote boroscopes and surface roughness standards to meet all defined requirements for the development program.



**B. X-Ray.**

This inspection method is used during the development program to provide data on the internal condition of the casting, initially to evaluate and quantify the effectiveness of the gating design, and secondarily to verify conformance to standards and specifications.

The development of the proper x-ray exposure techniques is a function of applying sound radiographic principles to the casting configuration in order to provide the sensitivity and coverage required for evaluation.

This method is used primarily in order to achieve the following:

1. Engineering evaluation, characterizing gate design and effectiveness, and identifying defect type, location and size.
2. Evaluation of the effectiveness of in process welding.
3. Final inspection verifying the casting conformance to standard and specification.

PCC has an extensive array of x-ray equipment. X-ray cabinets and vaults are configured to accommodate a wide variety of small to very large castings.

Energy capabilities low(300KV) to high (2MEV), enable us to x-ray to material thicknesses of up to 8 inches of steel sufficient to fully inspect castings to the quality requirements of this program.

PCC utilizes the highest quality grades of industrial x-ray film and employs automatic film processors to assure process uniformity and repeatability.

**C. Fluorescent Penetrant.**

This non-destructive test method is used extensively to evaluate the surface condition of castings through-out the manufacturing process.

PCC employs both class I and class II high sensitivity water washable fluorescent penetrants designed to be highly effective on cast surfaces and on the defect types normally encountered in castings.





PCC employs a semi-automated penetrant process line utilizing electrostatic penetrant application and automated penetrant removal methods, along with drying and developer application in a facility designed to handle castings of unusually large and complex configurations.

This system is designed to provide a high level of process uniformity and quality for consistent inspection.

This inspection method is utilized at the following points in normal manufacturing and casting development stages.

1. Preliminary engineering evaluation of development castings evaluating surface defect location, type , size and frequency.
2. Performed as a manufacturing inspection tool to evaluate the surface condition of the casting.

This method is utilized throughout the casting repair cycles at any point where the surface condition is subject to change.

3. Final inspection of the casting as a means to verify acceptance of the casting to requirements, standards and specifications.

D. Magnetic Particle Inspection.

PCC does not intend to perform this method of inspection on this casting material.

E. Ultrasonic Testing.

It is anticipated that PCC will evaluate this method for its potential application for dimensional inspection and verification of specific areas of the casting that may prove difficult or impossible to inspect by normally used dimensional inspection equipment and methods.

PCC does not intend this method to be used to evaluate, accept or reject castings for internal discontinuities.



## **TYPICAL INVESTMENT CASTING DEVELOPMENT PROCESS**

Included is a description of a typical development process for a large aircraft engine frame.

### **Duration**

- Samples within 1.5 - 2 years

- Production ready in 2 - 4 years from start

### **Design Review**

- Critical to program's success

- Provide general guidelines for castability

- Explain processes and identify producibility issues

### **Tooling**

- Wax injection dies

- Fixtures and Manipulators

### **Mockup Development**

- Establish part/alloy volumetric shrink factors

### **Gating Design of Experiments (DOE)**

- Dimensional and Metallurgical refinement

### **Tooling Modifications**

- To Adjust for learned volumetric shrink

- To provide required dimensional capability

### **Gate die/fixture construction**

- To provide for reliability and production quantities

### **Process DOE**

- To identify effect of process variation on quality



Fixed process certification

Process capability determination

To establish achievable tolerances

Fixed process demonstration

To provide samples for testing properties

Periodic cut-up evaluations

To compare to original demonstration samples

Production of castings under a fixed process.



## Dimensional Requirements

NASA Blueprint No. 96M66441

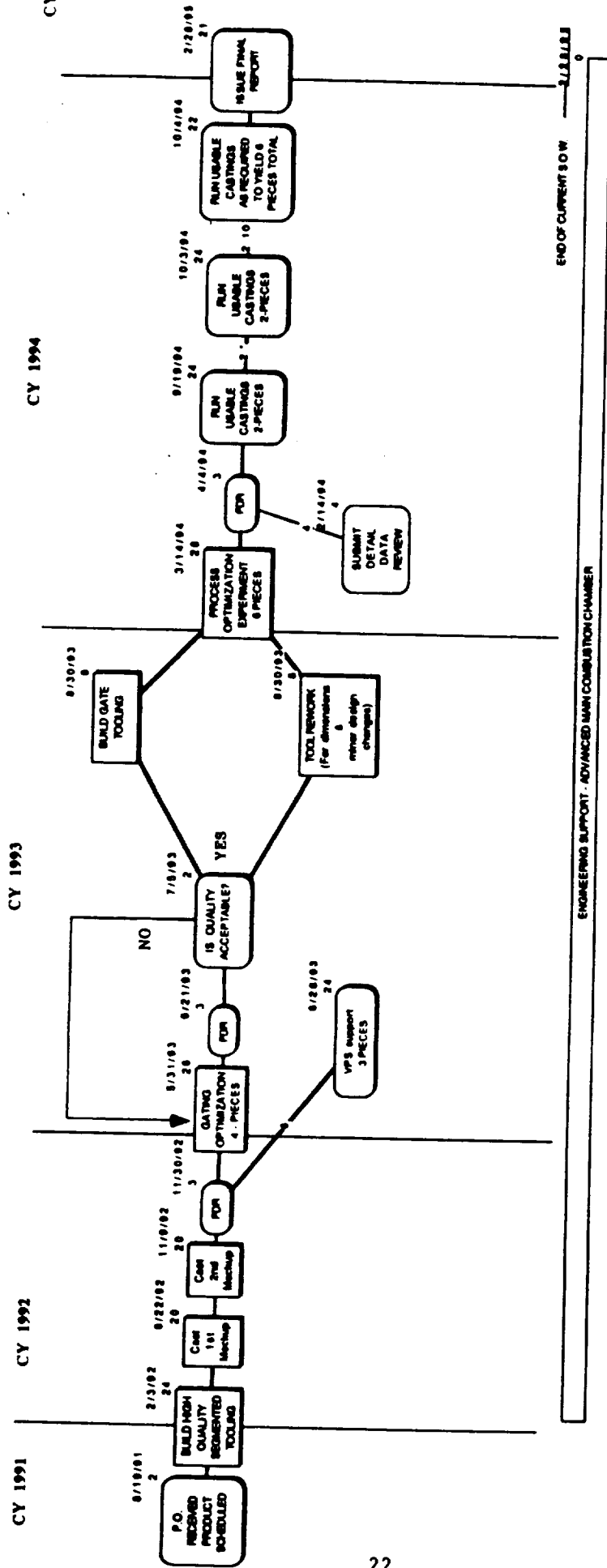
Dated February 11, 1991

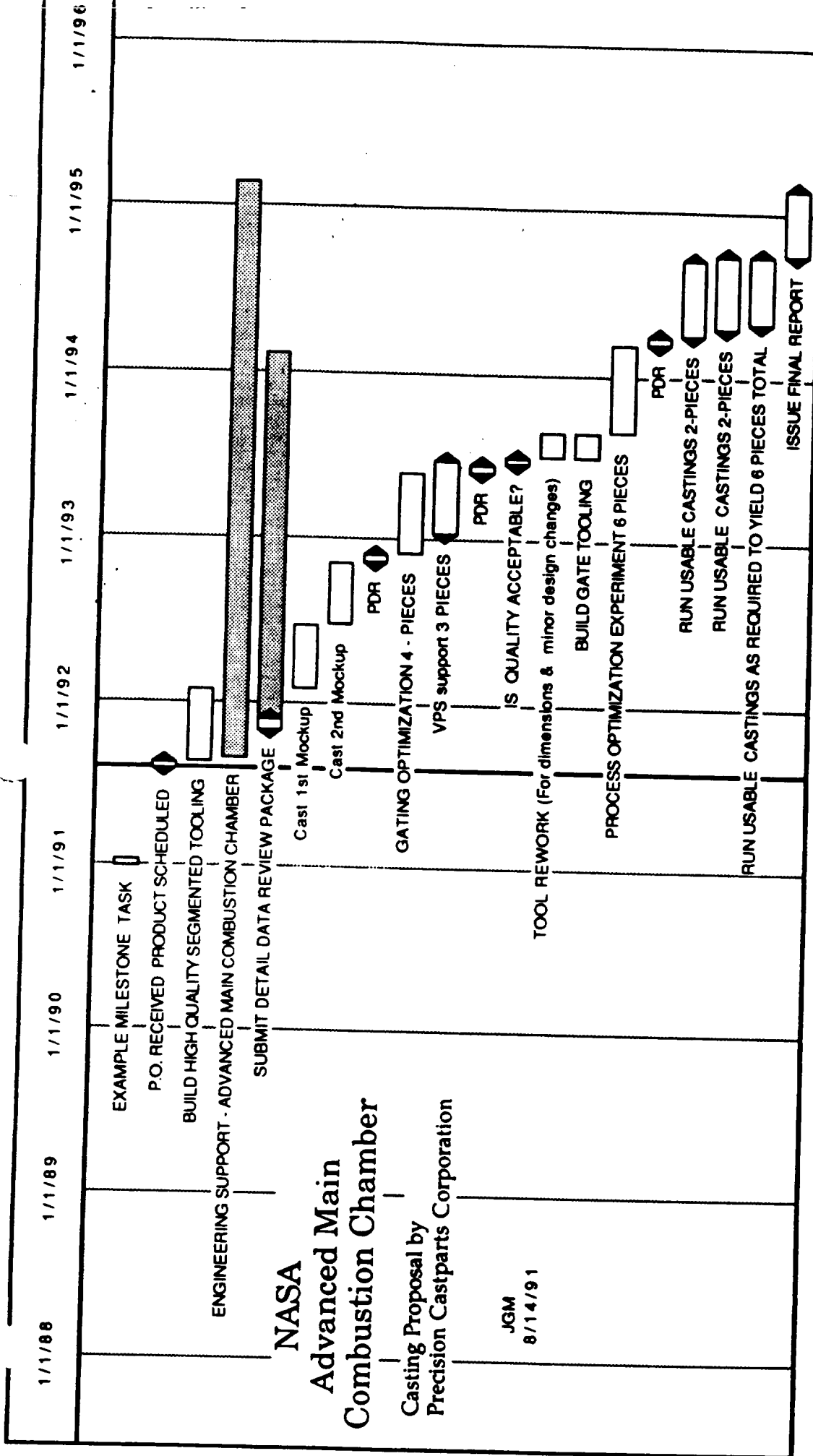
- 1) Blueprint tolerances for form and features remain to be established. The title block tolerance (B/P sheet 1) is unacceptable for this program. Final tolerances will be set by mutual agreement.
- 2) To ensure metallurgical integrity, detail "U", (B/P sheet 6, zone C-5) the 20.000 diameter groove, will be cast solid.
- 3) Tooling draft may be required for tool construction. Draft or wedge requirements will be agreed upon with NASA Engineers prior to tool construction.
- 4) The castings will require target machining to optimize the blue print dimensions. The target machining system will be on the Forward Manifold flange with welded target bosses.
- 5) Inspection of the Forward and Aft Manifold wall thickness requires "non-standard" equipment. Inspection of these wall thickness will require the approval of NASA Engineering and Quality and PCC Quality as to equipment and procedures to be used.
- 6) Tooling will be sized for volumetric shrink using JBK-75 material. A change to either NASA 23 or 718C will affect dimensional results.

**Tooling:** Wax pattern tooling will consist of three tools with inserts capable of producing three individual castings as defined by blueprint sheet 10, or a one piece configuration.

# NASA Advanced Main Combustion Chamber

## Casting Proposal by Precision Castparts Corporation







## **TECHNICAL PROPOSAL VOLUME 1, PART 3:**

### **FACILITIES:**

Located in Portland, Oregon are the Corporate Headquarters, Division Headquarters, Technical Center, and the Structural Divisions Investment Casting Foundries of Precision Castparts Corp. The Structural Division consists of three (3) manufacturing plants, which are the Small Structures Business Operation (SSBO), Titanium Business Operation (TBO), and Large Structures Business Operation (LSBO) and related satellite facilities required to support these manufacturing operations.

The NASA MSFC AMCC Casting Development program proposed by PCC would be performed at PCC's LSBO facilities. The LSBO facility is unmatched in the free world in its ability to manufacture very large structural investment castings. Currently LSBO produces aircraft quality castings for every major Jet Engine manufacturer in the free world. These parts range in weight from 150 to over 500 pounds ship weight, and are made in both air melt and vacuum alloys. LSBO has the capability of producing up to 10,000 pounds of master melt alloy in vacuum and up to 5,000 pounds in air.

LSBO has many unique pieces of equipment in its manufacturing operations. Including the largest wax press in the nation, three investing robots capable of lifting 5,000 pounds with accurate positioning of parts extended eight feet out in space, a dewax autoclave that will handle six foot diameter parts, and a vacuum casting furnace that will handle parts over six feet in diameter and six feet high, while operating at ten to the minus 6 (or lower) vacuum levels. The heat treat department can run, under vacuum, parts up to six feet in diameter and six feet high. We have, in our adjoining TBO facilities Hot Isostatic Pressing (HIP) facilities capable of handling castings up to forty-four inches in diameter and seventy two inches high, at temperatures of 2150°F with pressures of 15,000 psi.

LSBO's x-ray facilities include several 160-300 KVA units as well as two 1 MEV units and a 2 MEV linatron, mounted below ground, with automated part handling capability. In our penetrant inspection area we have electrostatic application equipment installed on a production line capable of handling the largest parts produced at LSBO.

Manual Layout Inspection and large CMM inspection capability exist with capacities in the six foot cube size range.



CNC machining facilities with part probing and pallet shuttle capability that will handle six foot cube size parts also exist at our satellite facilities.

Within the LSBO facilities exist some of the best in process welding facilities and certified welder capability in the nation. Our customer base recognizes this capability and consults with PCC on many unique welding problems.

On site at LSBO are the Division Metallurgical Laboratories, with all of the metal certification, metal proving and related testing facilities required to perform these services. When the work dictates the need, LSBO also utilizes qualified outside testing laboratories to augment its internal capability.

Every manufacturing process that will be required for this program either exists on site at LSBO or is readily available in the immediate area. Potentially we could send unique operations to fully (PCC) qualified off-site facilities if the production schedule dictates this requirement. This is considered to be a normal part of our manufacturing process and is done every day to support our customer delivery requirements.

#### **TRAVEL:**

The Rocket Engine and Space Component Development Engineering Team plans to travel to MSFC once each quarter for a program review, over the four year life of the program. Our proposal is based on five people traveling to each review. Each trip will require one day travel in each direction and will require one day at MSFC for our quarterly presentation. Two members of our team are not included in MSFC travel, our clerk would not be required and the health of our Project Engineer will not allow him to fly, so they are excluded. Sales participation as required will be funded by PCC.

#### **SUBCONTRACTS:**

PCC will subcontract for the tooling and fixtures required to perform the work outlined under this proposal. Tooling will consist of wax pattern molds and fixturing required to produce the individual casting configuration(s) required for the full cast AMCC. Our approach will be to tool the Forward Manifold, Jacket, and Aft Manifold as individual pieces (castings) with interchangeable inserts in the mating surfaces of each mold. This approach will allow us the flexibility of molding smaller individual components, while allowing the three





(3) individual wax patterns to be assembled into a one (1) piece configuration. This approach will provide a safe fall back position, should the one piece castings prove to be more difficult than we anticipated. This approach will assure NASA that we will be able to produce individual castings or combinations of Forward Manifold and Jacket or Aft Manifold and Jacket, while allowing the orderly (separate) development of the most difficult casting configuration.

PCC fully expects to ultimately produce this part as a one (1) piece casting.



## **TECHNICAL IMPLEMENTATION PLAN**

### **EQUIPMENT:**

PCC intends to fully utilize its available process equipment, hardware and test equipment normally used in casting development and manufacturing determined necessary to accomplish the goals of the development program.

PCC has evaluated and confirmed that its facilities, equipment and personnel are fully adequate to accomplish the tasks of this development program, except for specific fixtures as listed elsewhere.

PCC's significant equipment requirements necessary to accomplish this development program are defined below.

- Wax Injection Machines
  - Non-Standard

- Investing
  - Frames
  - Robotic Manipulators
  - Slurry Pots

- Autoclave

- Burnout Furnaces

- Casting Furnaces
  - Vacuum

- Shell Removal
  - Chemical KOH Tanks
  - Casting Manipulator
  - Manual Knockout Hand Tools
  - Automated Waterblast, Shotblast Cabinet and Systems

- Gate Removal
  - Automated Water Jet Cabinet
  - Manual Burnoff Torches

- Machining



#### **Surface Cleaning**

- Grit Blast Cabinet**
- Manual Grind (hand tool)**
- Belt Grinders**

#### **Inspection**

##### **X-ray**

- Fixtures, Support and Positioning**
- 300 KV (11 Cabinets and Vaults)**
- 2 MEV (1 Automated Unit)**
- 1 MEV (2 Cabinets)**

##### **Penetrant**

- Semi-automated Process Line**
- High Sensitivity Water Wash**

##### **Visual/Dimensional**

- Fixtures, Holding and Support**
- Automated Coordinate Measurement Machine**
- Manual Surface Plates**
- Ultrasonic Thickness Gage**

#### **Thermal Processing**

- Hot Isostatic Pressing Unit**
- Heat Treat Furnaces**
  - Vacuum**
  - Air**
  - Inert Gas in Retorts**



## **TECHNICAL PROPOSAL**

### **VOLUME 1, PART 4: KEY PERSONNEL**

Success or failure of a particular program or project often hinges on the availability of key personnel. Recognizing this in support of the Space Program, Precision Castparts Corp. (PCC) made the decision to create a dedicated team of Senior Development Engineers capable of performing complex engineering projects and managing their associated programs. This team is headquartered at PCC's Large Structural Business Operation (LSBO) and is dedicated to the development of Rocket Engine and Space Component investment castings.

#### **A. TEAM MEMBERS :**

Jerry Heman	- Project Engineer
Bruce Haphey	- Quality Engineer
John Davis	- Dimensional Engineer
Jeff Miller	- Part Engineer
Pam Wright	- Technician
Assigned	- Clerk
Steve Weber	- Program Manager
Myrna Nutting	- Sales Engineer

#### **B. BIOGRAPHY**

Jerry Heman  
Bruce Haphey  
John Davis  
Jeff Miller  
Pam Wright  
Steve Weber  
Myrna Nutting

#### **C. AVAILABLE TIME**

Estimated percentage of available time each team member will (on average annually) devote to this proposal are:



Jerry Heman	11%
Bruce Haphey	34%
John Davis	31%
Jeff Miller	41%
Pam Wright	37%
Clerk	15%
Steve Weber	19%

#### **D. TEAM BACKGROUND**

Jerry Heman has 25 years of Investment Casting experience. For the past 12 years he has worked in the Development Engineering side of the business at the Large Structural Business Operation (LSBO). Development Engineering at LSBO is on the cutting edge of casting development technology. All of the successful jet engine large structural super alloy investment castings in use today were developed in the Engineering Department of this facility.

Jerry is the Project Engineer for the Rocket Engine and Space Component Development Team. In this capacity he is able to use his past experience to assure on time, cost effective development of high quality castings by the team.

Bruce Haphey is a certified Level 3 Inspector with 22 years of Investment Casting experience. For the past 14 years he has been employed by PCC, holding positions where his Inspection and Quality experience could be applied to our business. For the past 3 years he has, as a Quality Engineer, specialized in accounts of customers who produce products for Government end use. For the past year he has been the Quality Engineer for the Rocket Engine and Space Component Development Team.

John Davis is a Dimensional Engineer with over 22 years of experience in the Investment Casting industry. For the past 13 years he has worked in Development Engineering at LSBO, where he was responsible for the Dimensional development of some of the most complex large structural castings produced at PCC. He has extensive experience in the application of segmented tooling and fixturing in the production of large complex investment castings. He is often called upon to provide customer training on dimensional application to their investment casting drawings and instructs new PCC employees in Dimensional Engineering principals.



Jeff Miller is a Part (Gating) Engineer with over 8 years experience with PCC (LSBO) in the Metallurgical Development of large complex super alloy investment castings. He is a leading proponent of, and an authority, in the use of statistical process control techniques and design of experiments in the development of complex castings. Jeff is often called upon to assist in trouble shooting casting problems other engineers are experiencing in the development of similar casting configurations.

Pam Wright is the Technician for the Rocket Engine and Space Component Development Engineering Team. She has over 5 years experience at PCC where she worked in Wax Cleaning, and in the Inspection Department as a CMM operator.

Steve Weber has 38 years of Manufacturing experience, the past 23 years of which are with PCC. At PCC he has held Manufacturing and Engineering Management Positions in Tool Design, Tool Construction, Process Engineering, Dimensional Engineering, Purchasing, Maintenance, Computer Aided Engineering, Technical Modernization and with the Rocket Engine and Space Component Development Engineering Team. Prior to forming this team, he managed a team that was devoted to the development of advanced Engineering Prototype technology, and for the prototype and demonstration of robotic work cells on the foundry manufacturing floor.

Myrna Nutting has over 4 years of experience with PCC. During that time she served very briefly as a secretary in the NDT department, and has spent the last four years as a Sales Engineer handling a wide variety of accounts which include all of the Rocket Engine and Space Components programs.



## **E. KEY PERSONNEL LISTING**

In addition to this proposal, the Rocket Engine and Space Component team members are key personnel on one (1) existing Government funded (ALS) contract and are planning to be utilized on one (1) additional Government funded (SSME) proposal.

At the time this proposal is being prepared, adequate man-hours exist to undertake this development effort. If outstanding proposals are funded as anticipated, in CY 1992 the projected load would be 98% of our average man-hour capacity. Even though the average man-hour requirement would be less than the actual available, two (2) key engineers (Dimensional and Gating) would, in reality, be overloaded and unable to carry the total man-hour requirement estimated for them. Should that prove to be the case, PCC will support the requirement as the load develops by hiring the necessary personnel and teaming them with the expert members of our team. We are confident that this type of an arrangement will facilitate the orderly casting development in each program.



## **BIOGRAPHY -- Jerry Heman**

### **EDUCATION:**

Bachelor of Science  
Portland State University  
1963

Many Technical and Management courses and training provided by PCC.

### **WORK EXPERIENCE:**

25 years in Investment Casting -- All at PCC.

13 years in Estimating with 10 as Chief Estimator

12 years in the Engineering Department, with two as Part and Product Engineer, one as a Cost Analyst, 8 years as a development team Program Manager, and the last year as a Project Engineer.





## BIOGRAPHY -- Bruce Haphey

### EDUCATION:

High School - 1957

Oregon State University  
Mechanical Engineering

Portland State University  
Mathematics

Linn-Benton Community College  
Non-destructive Testing  
Metallurgy  
Vacuum Technology  
Chemistry

Clackamas Community College  
Computer Science  
Statistical Process Control

### WORK EXPERIENCE:

22 years in Investment Casting

NDT Engineering -- Examiner Level III

Gating Engineer

Dimensional Engineer

Special Project Engineer

Quality Engineer



## BIOGRAPHY -- John H. Davis

### EDUCATION:

High School - 1960

2 years Oregon Polytechnical Institute

Additional College and Management courses  
1964 - Present.

### WORK EXPERIENCE:

4 years NDT and Destructive testing and Quality Control

22 years Investment Casting at PCC

11 years of engineering as Dimensional Engineer

11 years of Inspection as Layout, Dimensional, and NDT



## BIOGRAPHY -- Jeffrey G. Miller

### EDUCATION:

Oregon State University  
Bachelor of Science, Mechanical Engineering  
June 1982

OSU Foundation Grant  
June 1982

"Materials Selection DataBase"

A micro computer program for selection of materials based on design criterion. This project provided a system to catalog materials properties and to select "novel" materials rather than "common" ones. Programmed for a NorthStar Horizon Computer.

Engineer In-Training Certification  
June 1982

### WORK EXPERIENCE:

Precision Castparts Corp. LSBO  
Superalloy Investment Casting  
1983-4                      Production Engineer  
1984-5                      Pilot Area Facilitator  
1986-present              Development Engineer

I provided training in statistical process control to engineers and hourly employees. Responsibilities included development of subject matter and training materials, classroom and lab instruction, and project management and facilitation of employee involvement groups.

As a development engineer, I design gating, casting and manufacturing process to produce structural frames for aircraft engines. My responsibilities include working with jet engine designers to improve the castability of frame design, manufacture and delivery of prototype hardware. After engine certification, my responsibilities focus on product development for quality and cost objectives.



## BIOGRAPHY -- Pam Wright

### EDUCATION:

High School - 1967

Portland State University                      1967 - 1968

Clackamas Community College              1987 - Present

Presently I am three-quarters of the way through the Associate Degree Program for Investment Casting.

### WORK EXPERIENCE:

14 years experience with Pacific Northwest Bell -- Position included Service Representative, Service Analyst (Management position analyzing service performed to the customer) and Central Office Wiring.

5 years experience with Precision Castparts Corp. - Positions include: Wax Cleaning, Coordinate Measuring Machine Operator, and Technician for Rocket Engine and Space Component Development Engineering Team.



## BIOGRAPHY -- Steve Weber CMFGT

### EDUCATION:

High School - 1953

Served 6 year Machinist and Toolmaker

Apprenticeship - Journeyman Toolmaker 1968

SME Certified - CNFGT -- 1973

Many College level Technical and Management training  
courses - 1960 - Present

### WORK EXPERIENCE:

15 years of Manufacturing and Management prior to  
employment at PCC.

23 years of Investment Casting -- at PCC

20 years in Manufacturing and Engineering Management.  
Positions included, Manager of Tool Design, Tool  
Manufacturing, Dimensional Engineering, CAD CAM  
Design Engineering, Maintenance, Technical  
Modernization, Advanced Prototype Development.

1989 - Present -- Program Manager

Rocket Engine and Space Component Development  
Engineering Team. Currently developing Main  
Combustion Chamber Castings for ALS and SSME  
Programs in JBK-75 alloy.



## **BIOGRAPHY -- Myrna Nutting**

### **EDUCATION:**

High School - 1977

Bachelor of Arts

Lewis and Clark College

1980

PCC Sales Engineer Training Program - 1987

Intensified training in all areas/departments of the investment casting process.

Post graduate work in Business Administration, Economics, Finance, Marketing, and related technical courses.

### **WORK EXPERIENCE:**

4 years as Manager of women's clothing boutique.

2 years as full-time mother.

2 years as Assistant Account Manager, Nike.

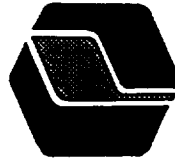
1987 - Present -- Sales Engineer, Large Structurals Business Operation. Account responsibilities include all Rocket and Space Component customers, Allison Gas Turbines, Westinghouse, all impeller accounts, and any new customers in Southern California.

**PRELIMINARY DESIGN REVIEW**  
**AMCC CASTING DEVELOPMENT**

**August 26, 1992**

**PRELIMINARY DESIGN REVIEW AGENDA  
AMCC CASTING DEVELOPMENT  
WEDNESDAY, AUGUST 26, 1992**

INTRODUCTION	STEVE WEBER	8:15-8:30
TOOLING & DIMENSIONAL ENGINEERING	JOHN DAVIS	8:30-9:30
BREAK		9:30-9:45
PART ENGINEERING (Lots 1-3)	JEFF MILLER	9:45-10:30
NDT ENGINEERING	BRUCE HAPHEY	10:30-11:15
LUNCH		11:30-12:30
PART MANUFACTURING (Lots 1-3)	JEFF MILLER	12:30-2:00
BREAK		2:00-2:15
GATING DOE PARTS (Lots 10-13)	JIM HOWCROFT	2:15-3:30
QUALITY ISSUES	BRUCE HAPHEY	3:30-4:00
SUMMARY	STEVE WEBER	4:00-4:05
DISCUSSION & ACTION ITEMS	ALL	4:05-4:30



**Precision Castparts Corp.**

**NASA**



# PRECISION CASTPARTS CORP.

PRESENTATION TO

**NASA**

August 26-27, 1992

## Introductions

### PCC AMCC Development Team

Pam Wright, Engineering Technician

John Davis, Dimensional Engineer

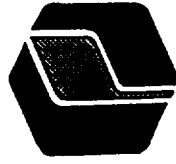
Bruce Haphey, Quality Engineer

Jim Howcroft, Part Engineer

Jeff Miller, Part Engineer

Jon Down, Account Manager

Steve Weber, Program Manager



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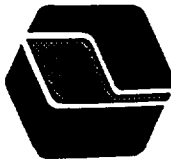
**NASA**

## PROGRAM OBJECTIVE

PRODUCE A STRUCTURAL JACKET AND COOLANT  
MANIFOLD CASTING DESIGN THAT IS:

- MORE RELIABLE
- MORE PREDICTABLE
- MORE COST EFFECTIVE

THAN THE WROUGHT, MACHINED, AND HEAVILY WELDED  
DESIGN USED FOR THE CURRENT SSME MAIN  
COMBUSTION CHAMBER (MCC).



**Precision Castparts Corp.**

**NASA**

# TOOLING

JOHN DAVIS

- TOOLING CONSTRUCTION
- DIMENSIONAL DEVELOPMENT
- GENERATION OF DIMENSIONAL DATA



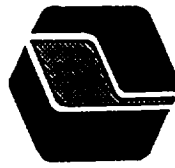
Precision Castparts Corp.

NASA

# **PART ENGINEERING STRATEGY**

**JEFF MILLER**

- **GATING**
- **STRATEGY FOR LOTS 1, 2, & 3**
- **HOW LESSONS LEARNED FROM EACH CASTING ARE APPLIED TO THE NEXT**



**Precision Castparts Corp.**

**NASA**

# **NON-DESTRUCTIVE TESTING**

**BRUCE HAPHEY**

- **PCC EXPERIENCE**
- **PCC CAPABILITIES**
- **ADVANTAGES OF TECHNOLOGIES**
- **LIMITATIONS OF TECHNOLOGIES**



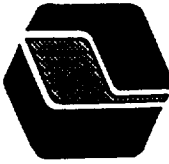
**Precision Castparts Corp.**

**NASA**

# PART MANUFACTURING

JEFF MILLER

- LOTS 1 & 3 --  
ALL PHASES OF INVESTMENT CASTING PROCESS
- LOT 2  
(SHOW & TELL CASTING)-- GENERIC STEPS TO  
PRODUCE



Precision Castparts Corp.

NASA

**GATING DOE  
JIM HOWCROFT**

- CRITICAL PHASE OF THE DEVELOPMENT PROGRAM
- RESULTS FROM DESIGNED EXPERIMENT WILL PROVIDE THE BASIS FOR ALL FUTURE WORK
- IF DOE IS SUCCESSFUL, ALL FUTURE AMCC CASTINGS WILL BE MANUFACTURED UTILIZING THE GATING SYSTEM WHICH WAS DETERMINED TO PRODUCE THE BEST RESULTS FROM THIS EXPERIMENT



**Precision Castparts Corp.**

**NASA**

# QUALITY ISSUES

BRUCE HAPHEY

- PCC QUALITY SYSTEM
- APPLICATION IN A PRODUCTION ENVIRONMENT
- SYSTEMS THAT WORK IN THE COMMERCIAL WORLD
- SYSTEMS THAT ARE UNWIELDY IN AN INDUSTRIAL ENVIRONMENT



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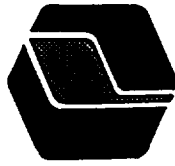


# DIMENSIONAL DEVELOPMENT

NASA AMCC

## OBJECTIVE:

- To establish a dimensional database for this casting
- To characterize the process capability for the JBK-75 alloy in this configuration.
- To establish dimensional requirements for the final blueprint.
- To determine volumetric shrinkage in order to construct production tooling.



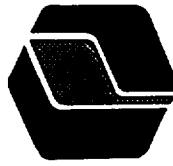
**Precision Castparts Corp.**

**NASA**

## TOOLING NASA AMCC

TEMPORARY TOOLING BUILT FOR THIS PROGRAM BECAUSE:

- Volumetric shrink for this alloy and configuration unknown
- Final configuration not established



**Precision Castparts Corp.**

**NASA**

# TEMPORARY TOOLING ADVANTAGES

NASA AMCC

- Faster construction time
- Lower cost to manufacture vs. production tooling
- Flexibility -- Can accommodate size and configuration changes



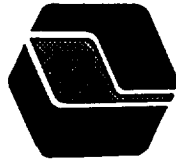
**Precision Castparts Corp.**

**NASA**

# BASELINE VOLUMETRIC SHRINKAGE FOR TOOLING

BASELINE VOLUMETRIC SHRINKAGE OBTAINED FROM OTHER  
CASTINGS PRODUCED IN JBK-75 ALLOY

- G.E. GF 6-50 CRF
- ROCKETDYNE SSME MANIFOLDS
- ROCKETDYNE DEMONSTRATION THROAT CASTING
- NLS AFT MANIFOLD



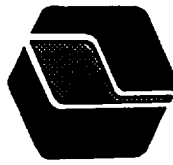
**Precision Castparts Corp.**

**NASA**

# TOOLING PLAN

## NASA AMCC

- Tooling and fixturing designed for maximum size flexibility
- Assembled wax pattern made from three basic subassemblies:
  - Forward Manifold=360° ring with wax welded manifold caps
  - Jacket=1/6 segment
  - Aft Manifold=1/6 segment with wax weld details

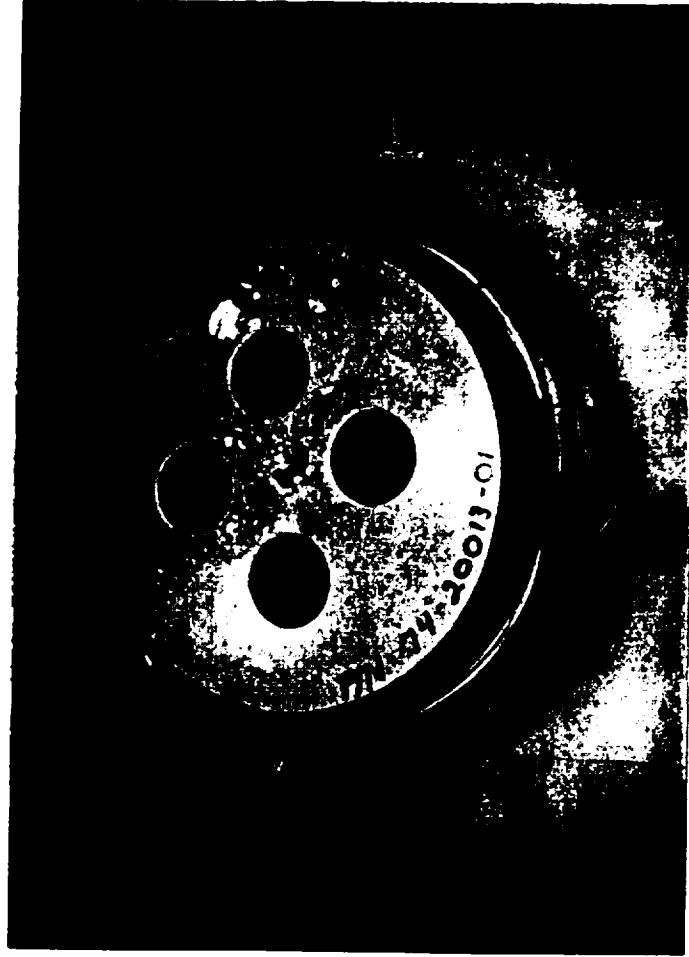


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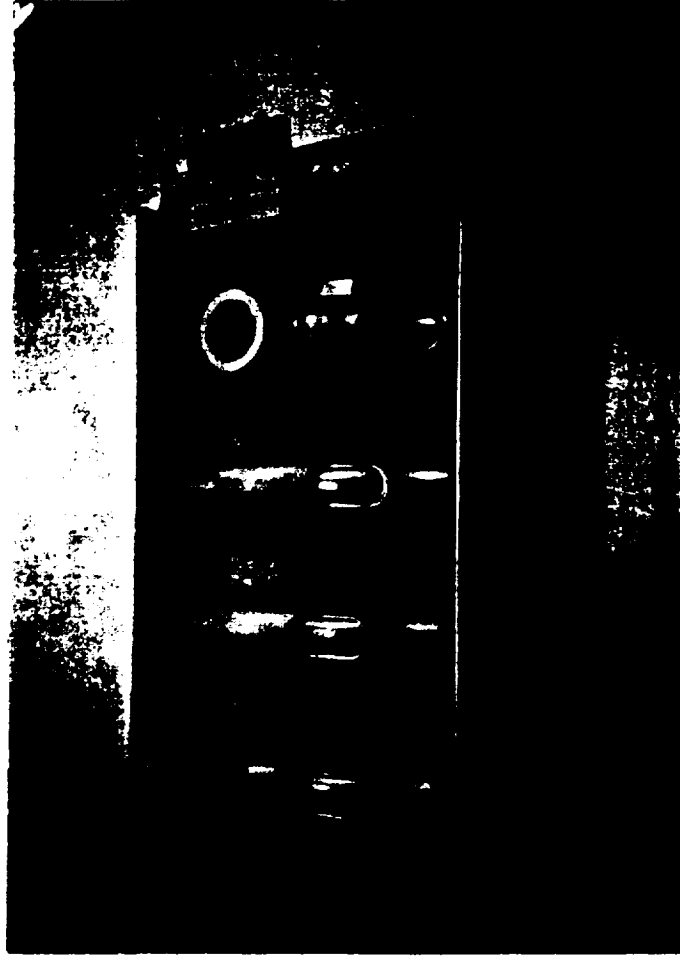
**NASA**

# FORWARD MANIFOLD

NASA AMCC



360° CENTER SECTION  
(shown on support fixture)



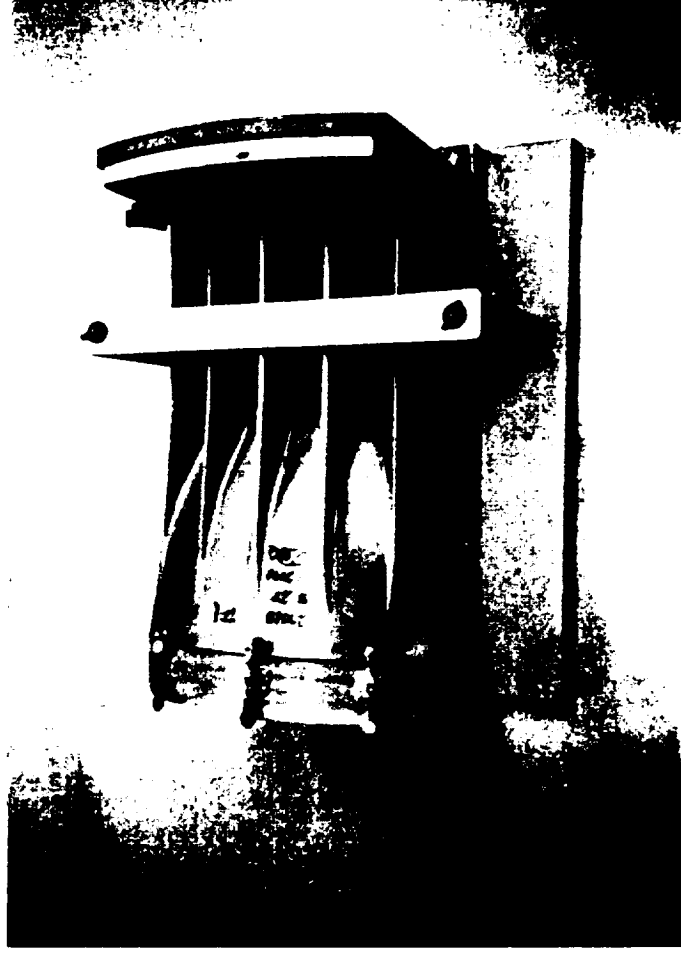
TYPICAL WAX MANIFOLD CAPS  
(shown on support fixture)



Precision Castparts Corp.

NASA

# JACKET SECTION NASA AMCC



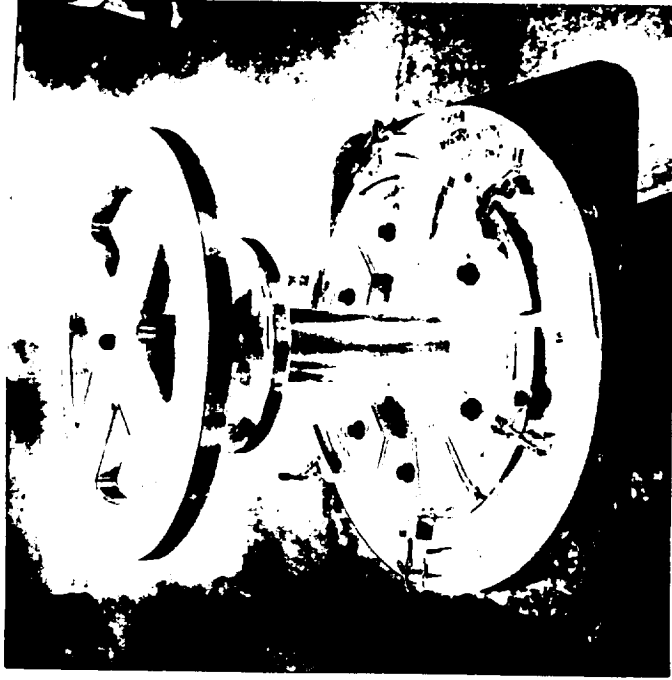
1/6 SEGMENT  
(shown on support fixture)



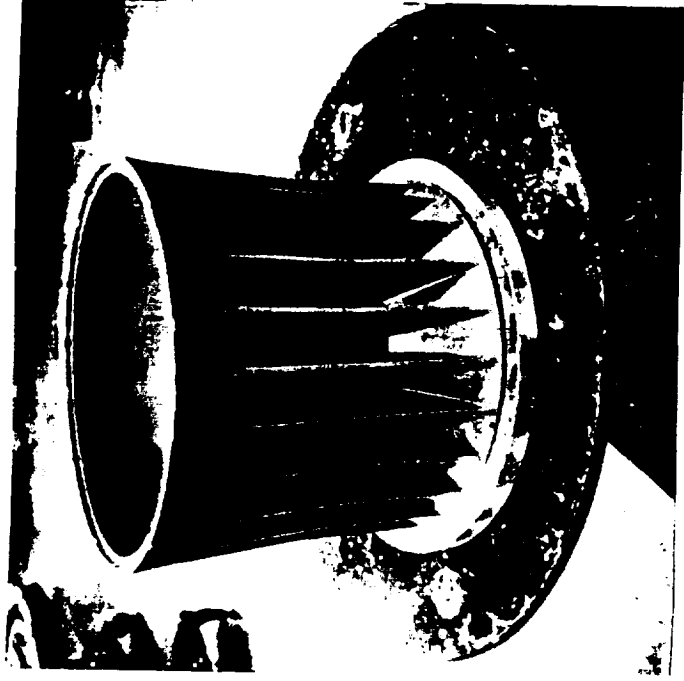
Precision Castparts Corp.

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# JACKET SECTION NASA AMCC



PATTERN ASSEMBLY FIXTURE



ASSEMBLED PATTERN



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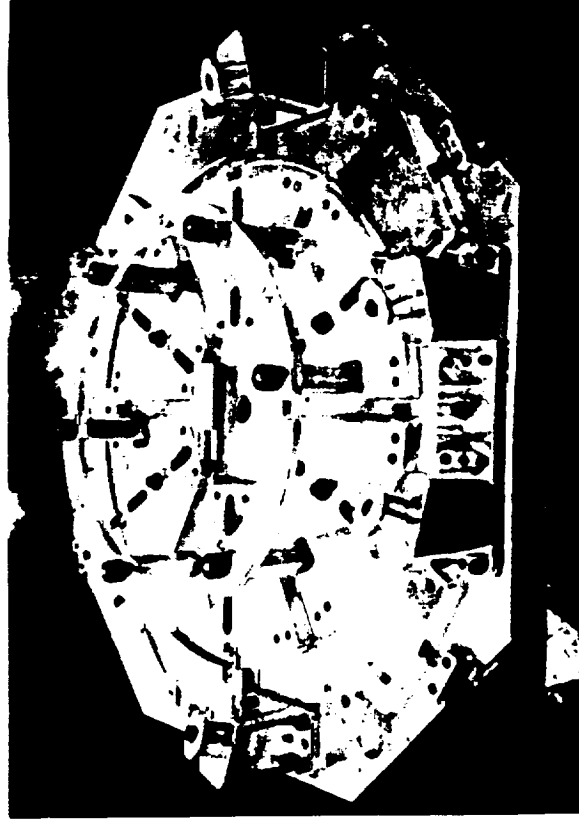


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# AFT MANIFOLD NASA AMCC



1/6 SEGMENTS  
(shown on support fixture)



PATTERN ASSEMBLY FIXTURE

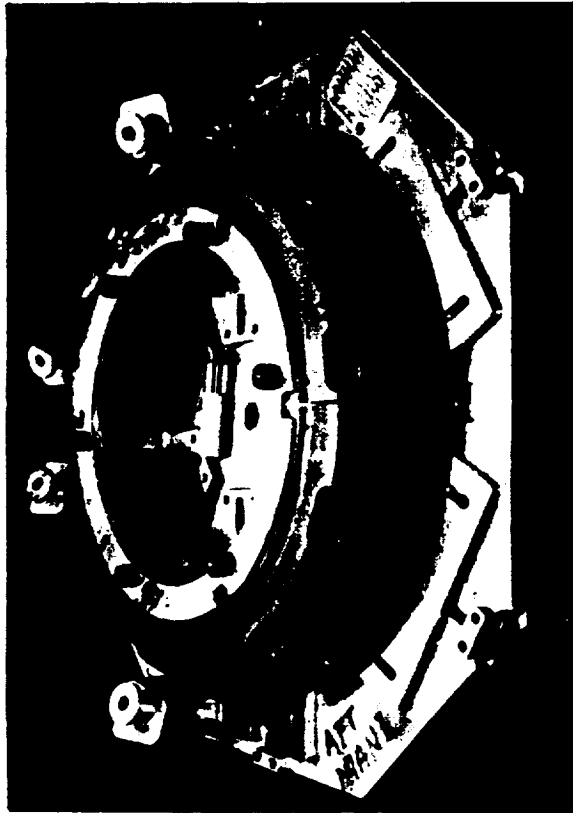


Precision Castparts Corp.

NASA

**AFT MANIFOLD  
NASA AMCC**

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OF POOR QUALITY



**FIXTURE AND PATTERN**



**Precision Castparts Corp.**

**NASA**

# PATTERN ASSEMBLY FIXTURE

## NASA AMCC



**PATTERN ASSEMBLY FIXTURE**  
Fixture positions each wax component  
on centerline and axial locations



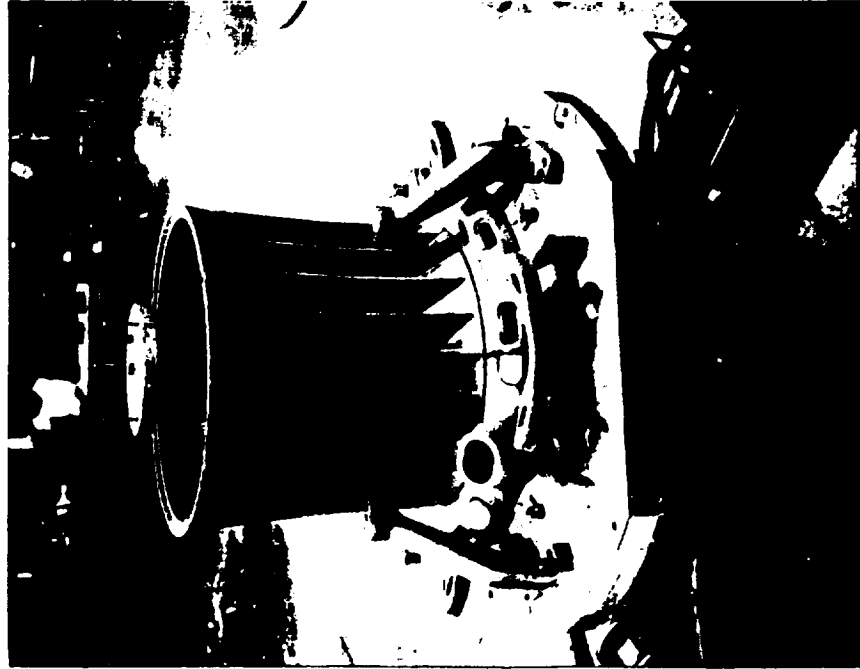
**AFT MANIFOLD IN FIXTURE**



**Precision Castparts Corp.**

**NASA**

# WAX PATTERN NASA AMCC



JACKET SECTION IN FIXTURE



FORWARD SECTION IN FIXTURE



**Precision Castparts Corp.**

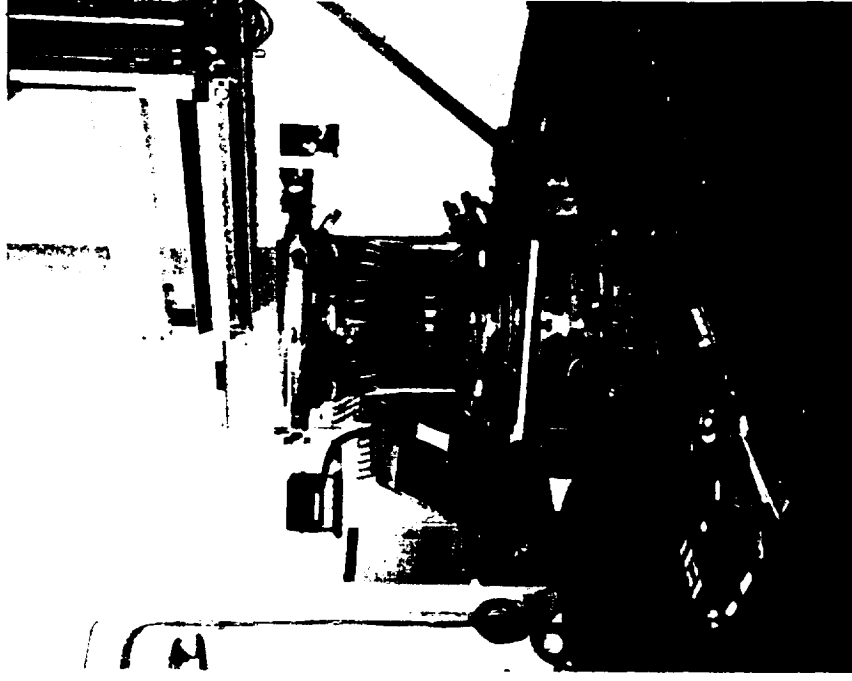
**NASA**

# PATTERN FINISHING & INSPECTION

## NASA AMCC



COMPLETE WAX PATTERN IN  
FIXTURE READY FOR PATTERN  
FINISHING  
(Tilt, Rotate)



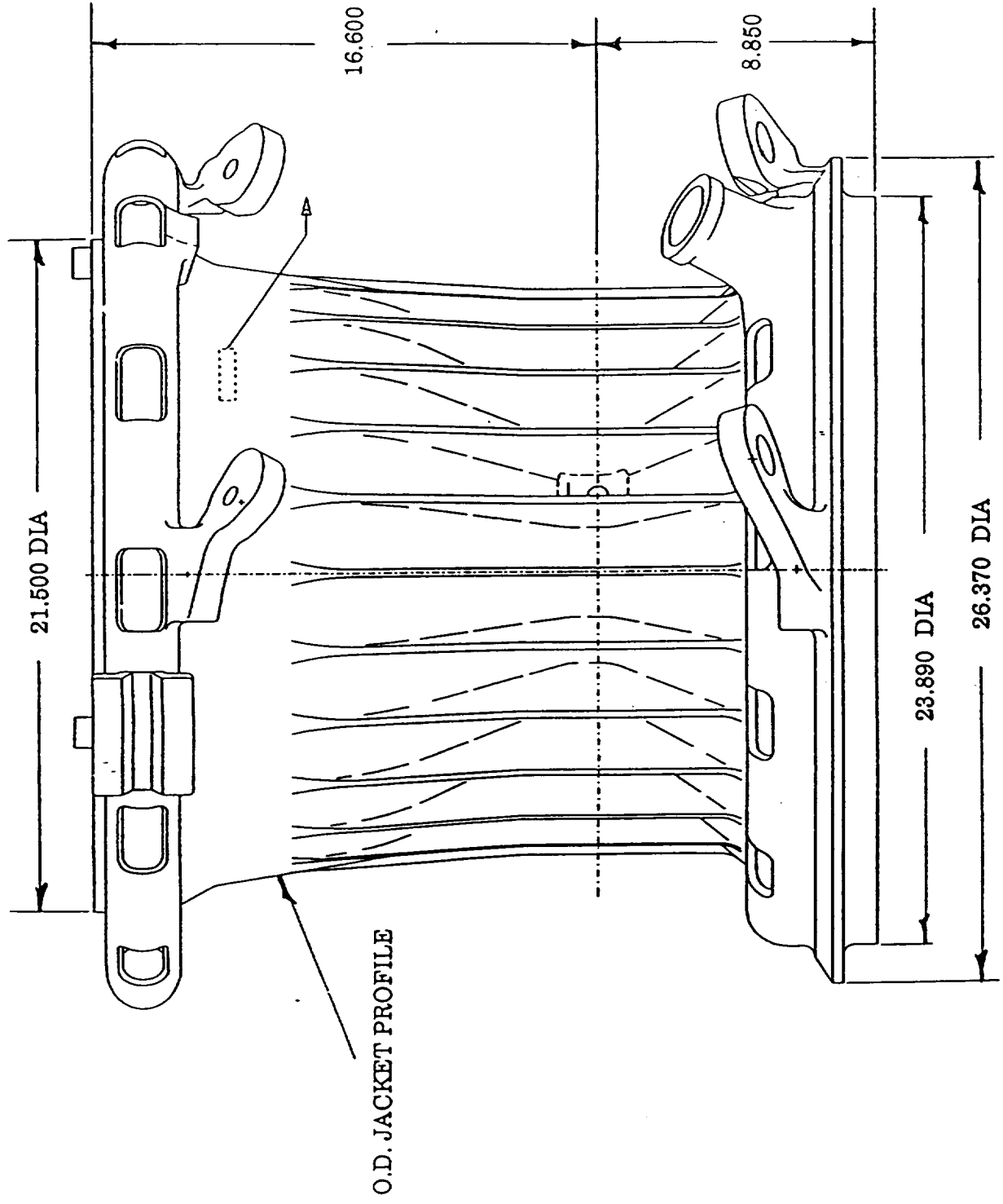
COORDINATE MEASURING  
MACHINE (CMM) USED FOR  
DIMENSIONAL INSPECTION  
OF WAX PATTERNS AND METAL  
CASTINGS



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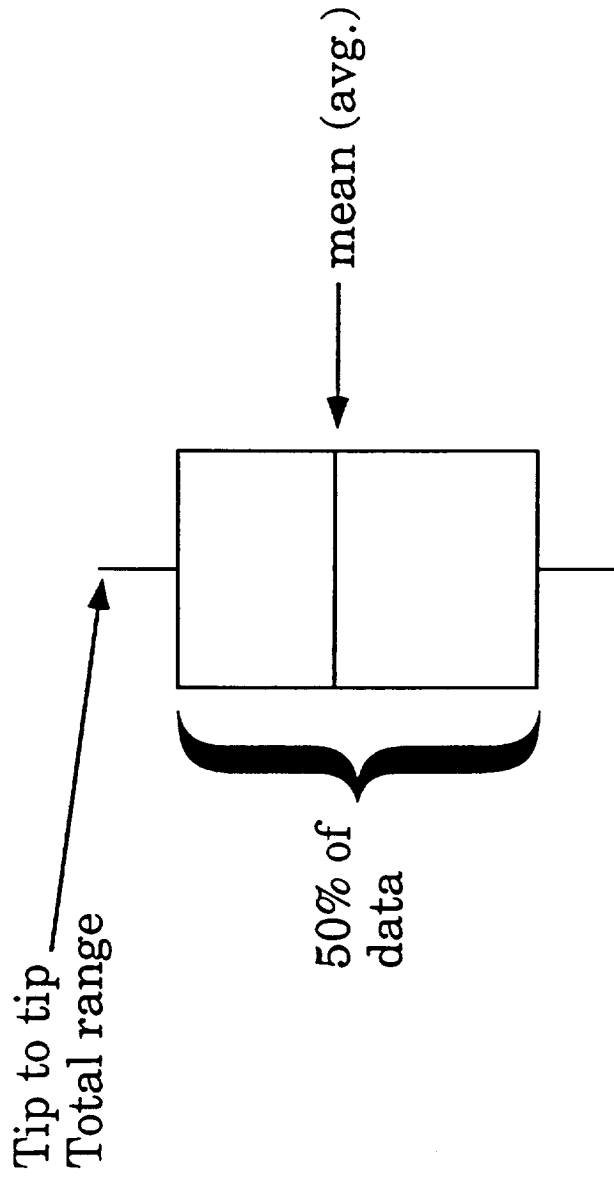
# NASA AMCC BLUEPRINT DIMENSIONS



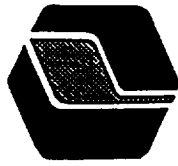
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# STATISTICAL PROCESS CONTROL BOX AND WHISKER SYMBOL DEFINITION



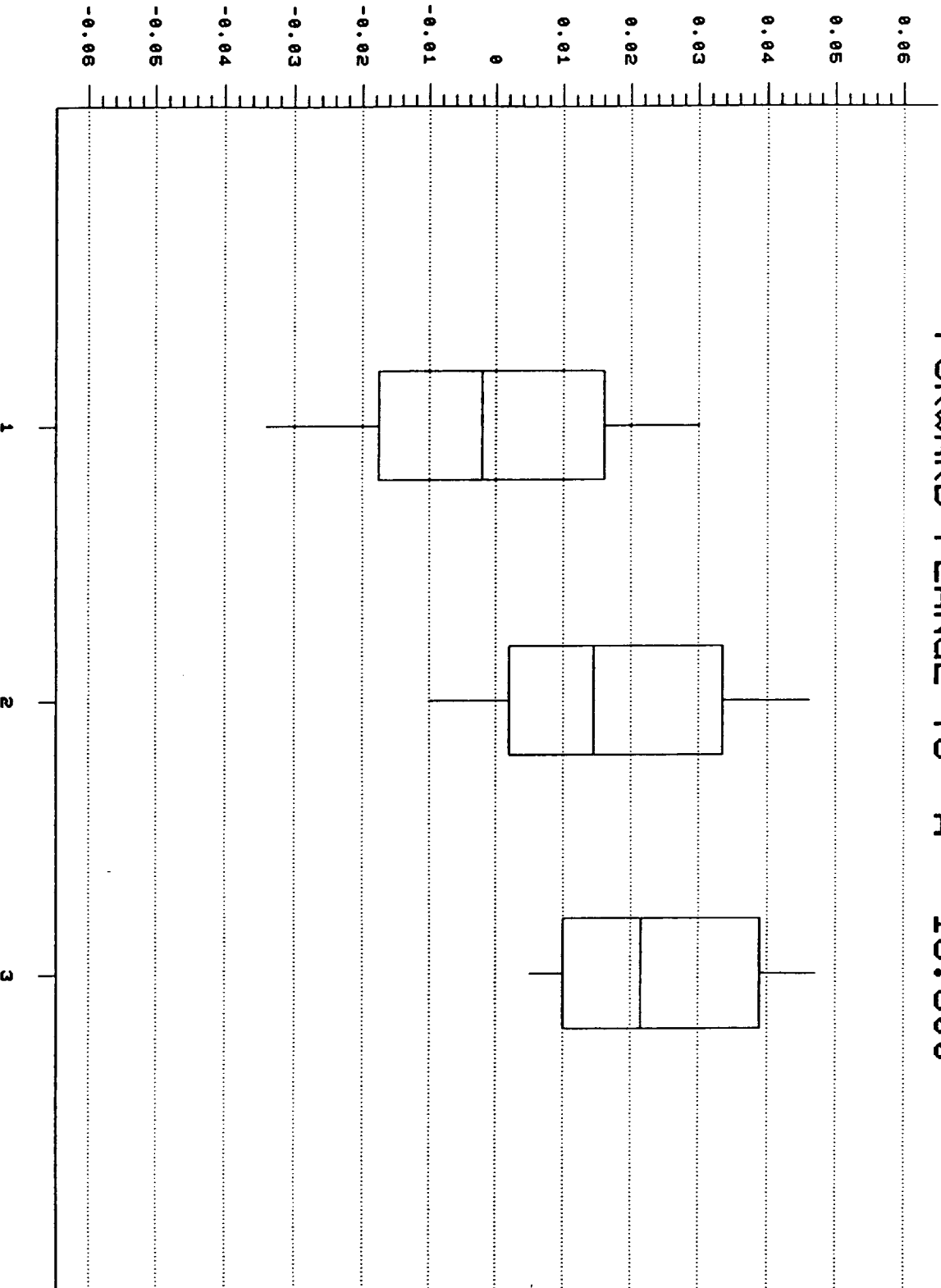
All data analyzed by Statgraphics



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# Multiple Box-and-Whisker Plot FORWARD FLANGE TO -A- 16.600



DEVIATION



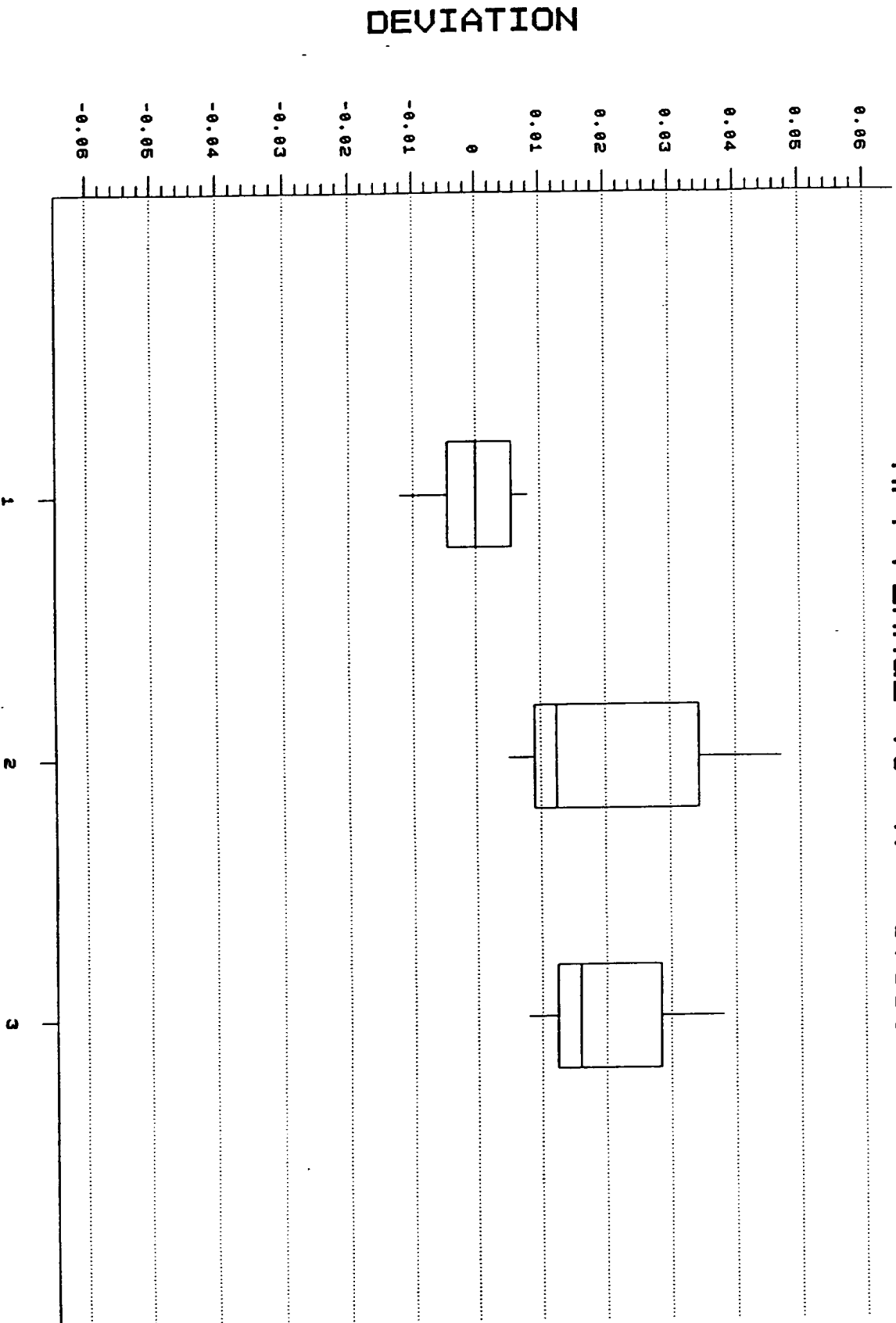
Precision Castparts Corp.

SERIAL NUMBER

NASA



# Multiple Box-and-Whisker Plot AFT FLANGE TO -A- 8.850

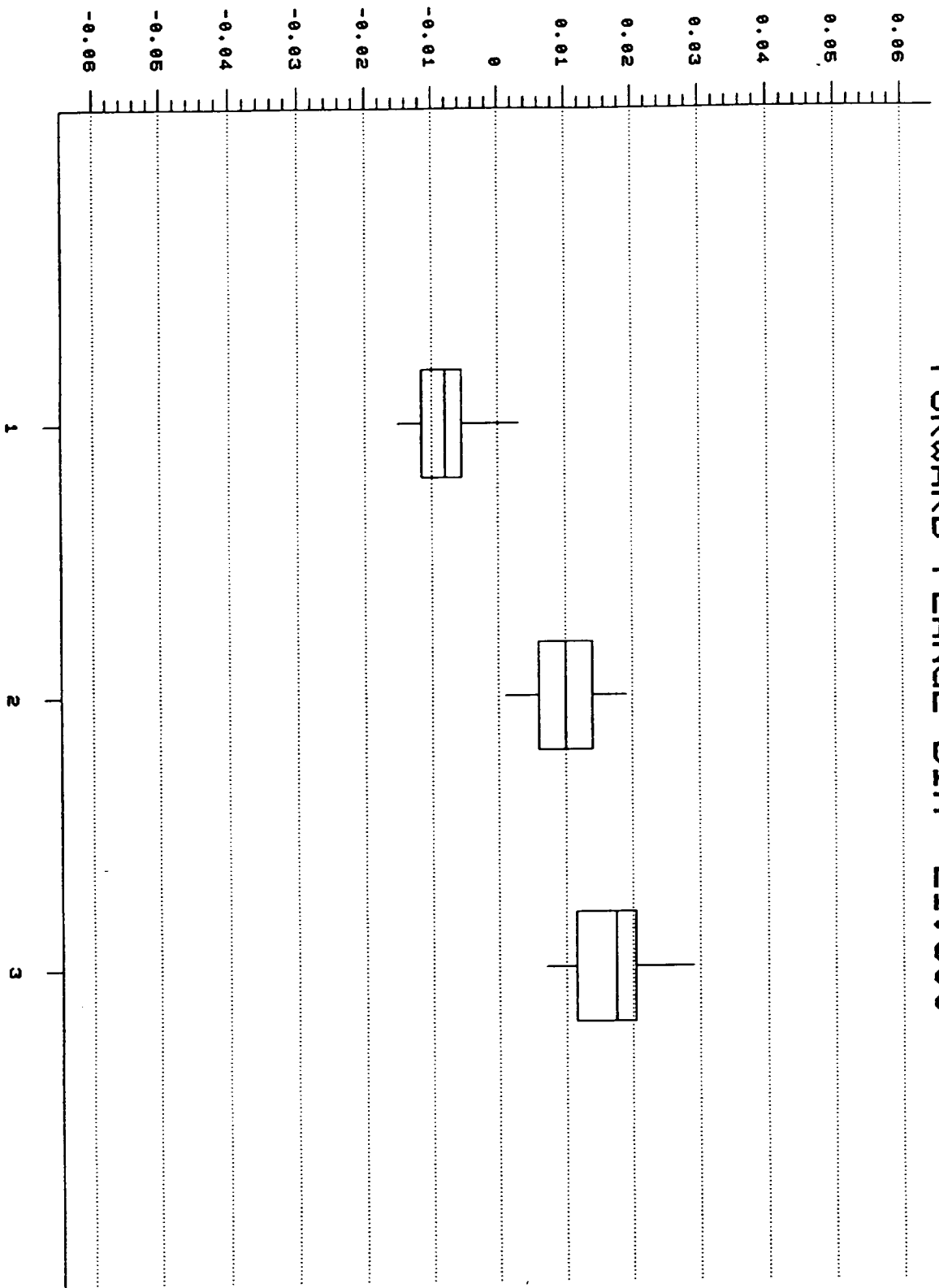


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SERIAL NUMBER

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Multiple Box-and-Whisker Plot  
FORWARD FLANGE DIA 21.500



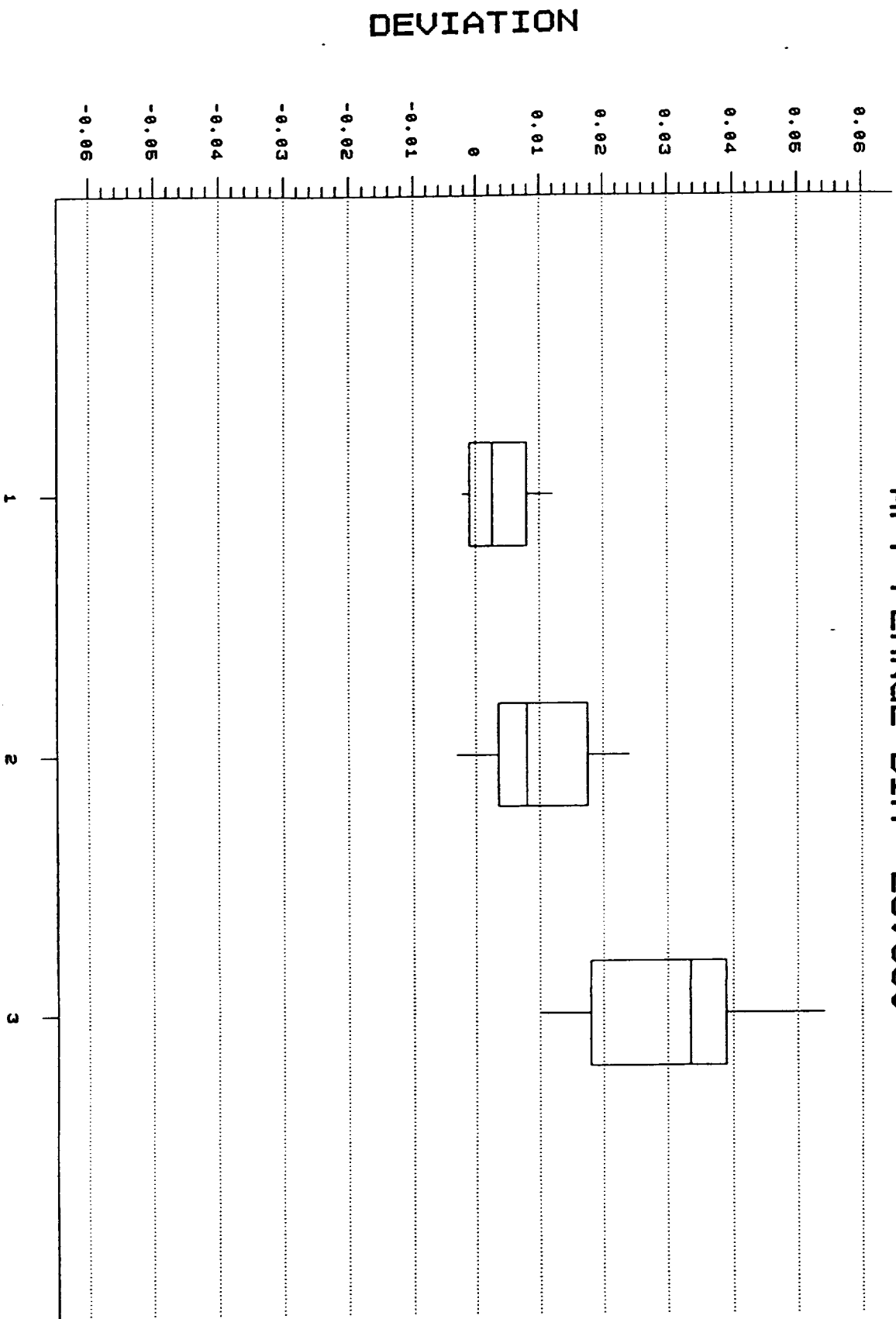
Precision Castparts Corp.

SERIAL NUMBER

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# Multiple Box-and-Whisker Plot

## AFT FLANGE DIA 23.890

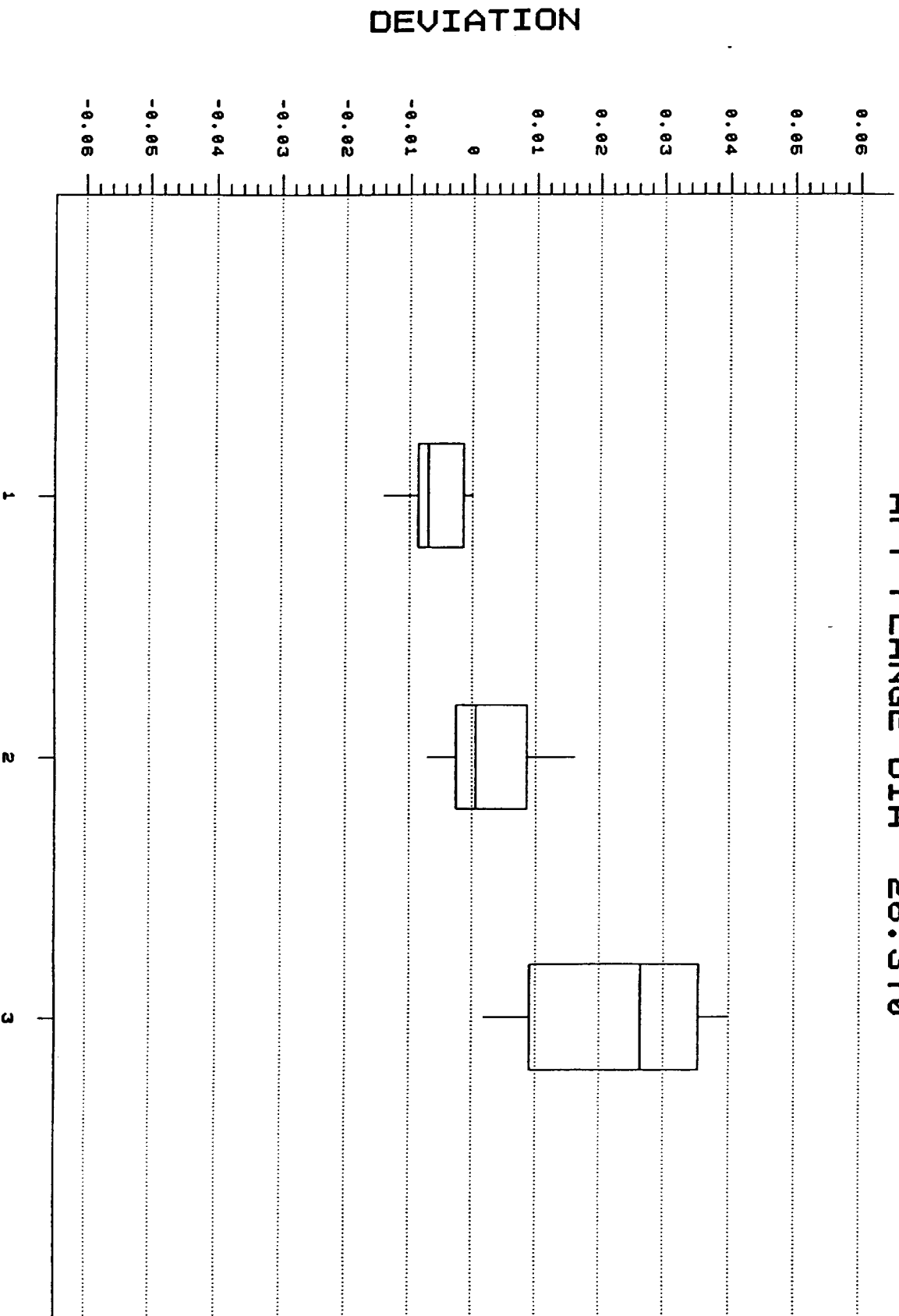


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Multiple Box-and-Whisker Plot  
AFT FLANGE DIA 26.370

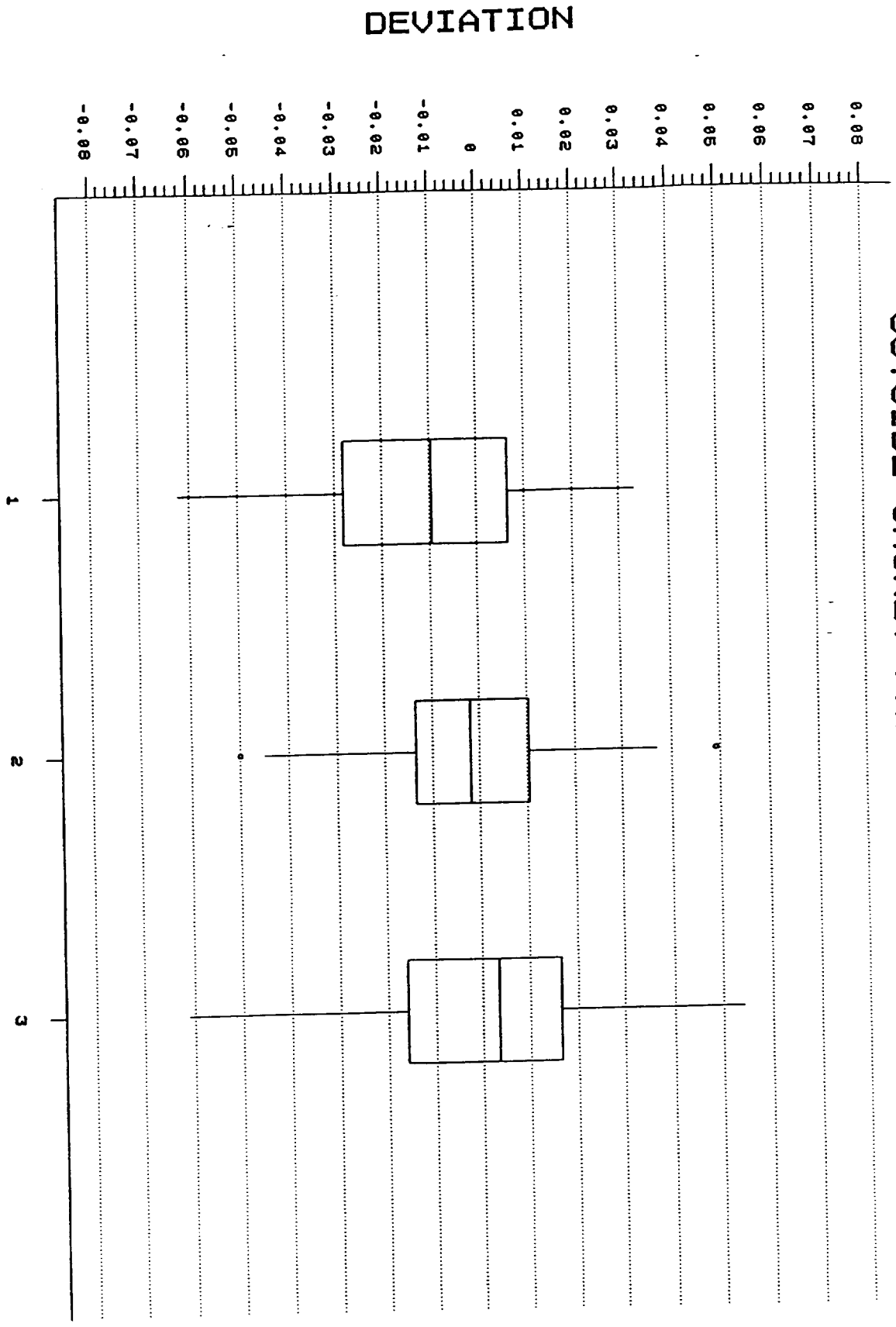


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SERIAL NUMBER

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Multiple Box-and-Whisker Plot  
OUTSIDE JACKET PROFILE 0.160 TO ABC



Precision Castparts Corp.

SERIAL NUMBER



# PART ENGINEERING

- DESIGN
- DEVELOPMENT PROCESS
- PART ENGINEERING
- INVESTMENT CASTING
- GATING

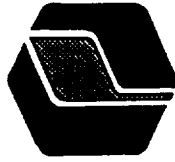


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# DESIGN

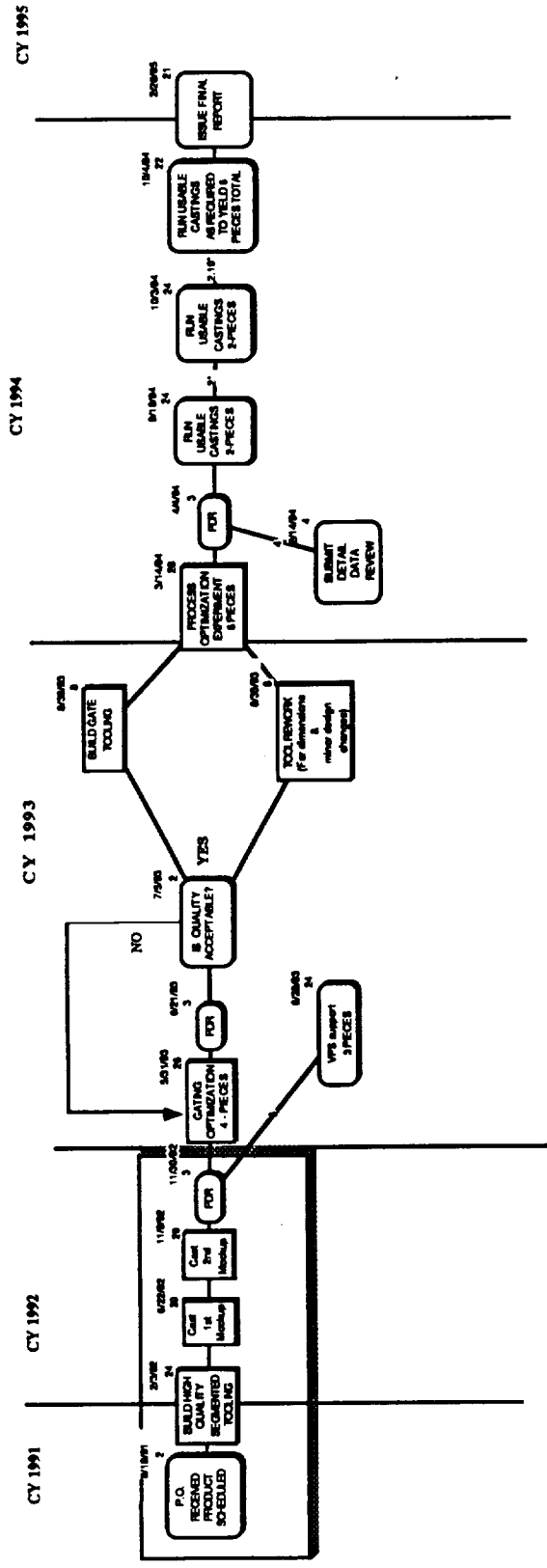
- PROVIDE MANUFACTURING INPUT
- PRODUCEABILITY - ceramic cores for FWD manifold
- QUALITY - shape/location of windows
- COST REDUCTION - standard HIP / heat treat cycles
- “DEVELOP FOR PRODUCTION” PHILOSOPHY
- USE PRODUCTION READY PROCESSES
- FOLLOW INDUSTRY/L.S.B.O. STANDARDS
- ASSESS DIMENSIONAL AND METALLURGICAL CAPABILITY



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# DEVELOPMENT PROCESS



• ENGINEERING SAMPLES

• GATING OPTIMIZATION DOE

• PROCESS SENSITIVITY DOE

• PROTOTYPE PARTS = PROCESS DEMONSTRATION

• ADDITIONAL "BEST EFFORT" CASTINGS



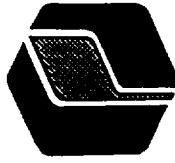
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# ENGINEERING SAMPLES

- Evaluate various manufacturing techniques (yield and product quality)
- Evaluate several gating ideas
- Collect information to establish part/alloy volumetric shrinkage
- Experience making JBK-75 alloy
- Experience fabrication welding
- Initiate development of inspection methods (NDT)
- Develop prototype fixturing and handling techniques

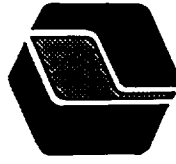


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# **PART ENGINEERING - PART OF THE TECHNICAL TEAM**

- **OTHER PART ENGINEERS**
- **PCC TECHNICAL CENTER**
- **PROCESS ENGINEERING**
- **PROCESS CONTROL ENGINEERING**
- **QUALITY ENGINEERING**



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# PART ENGINEERING - ACTIVITIES

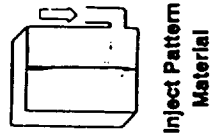
- RESEARCH LIKE GATING
- DEVELOP GATING SYSTEMS
- ISSUE TECHNIQUE CARDS
  - Casting
  - Gate Removal
- REVIEW AND APPROVE TECHNIQUE CARDS
- MONITOR PROCESS
  - Shell Making
  - Casting
  - NDT
  - Repair
- REQUEST DESIGN OF GATE DIES



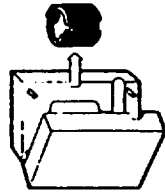
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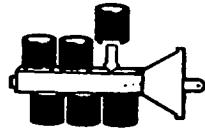
# INVESTMENT CASTING



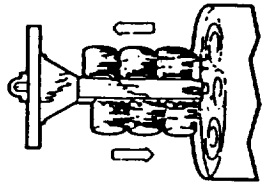
Inject Pattern Material



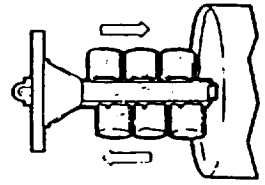
Remove Pattern



Assemble Cluster



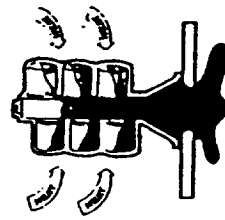
Drip or Invest



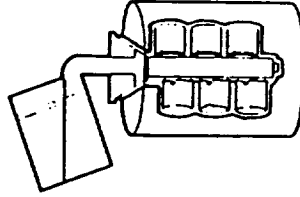
Stucco



Dewax the Shell Mold



Fire the Shell Mold



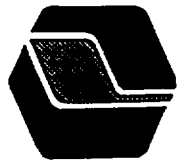
Cast



Knockout and Finish



Coating Pattern

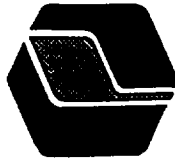


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# GATING BASICS

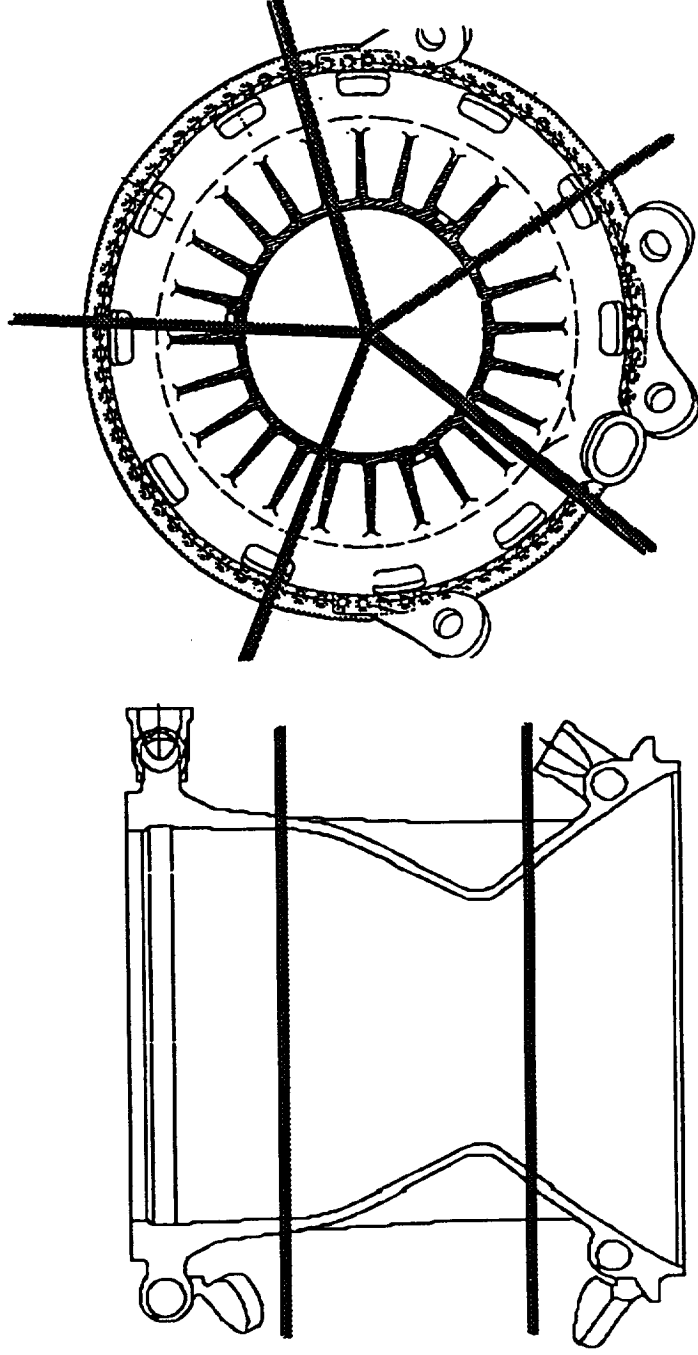
- ELIMINATE MICROSHRINKAGE - Directional Solidification
- FILL THE MOLD; Turbulence, Temperature Distribution of Liquid
- USE INSULATION TO ENHANCE THE THERMAL GRADIENTS
- BE AWARE OF THE EFFECT OF GATING ON MOLD MAKING
- LEARN FROM EACH EXPERIENCE AND DEFINE NEW TRIALS



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# DIVIDE THE CASTING INTO LOGICAL SEGMENTS

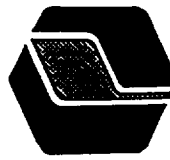
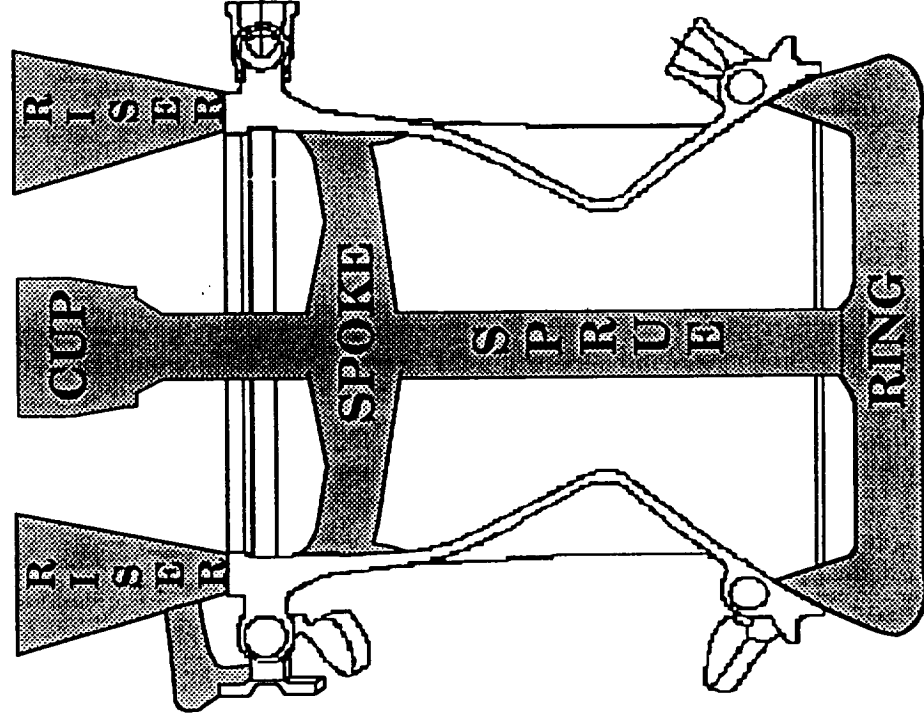


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# GATING

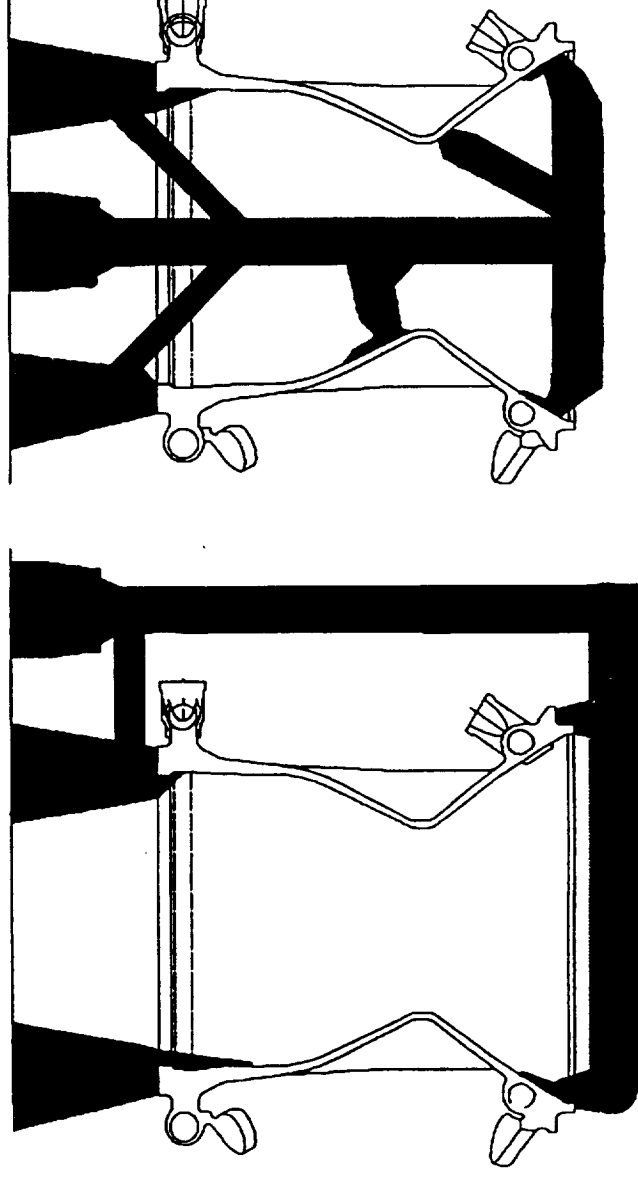
## GATING COMPONENTS



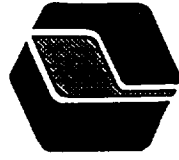
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# IDENTIFY SEVERAL STYLES OF GATING BASED ON EXPERIENCE



- DETERMINE SIZE OF GATING COMPONENTS
- TRY SEVERAL CONTACT SHAPES

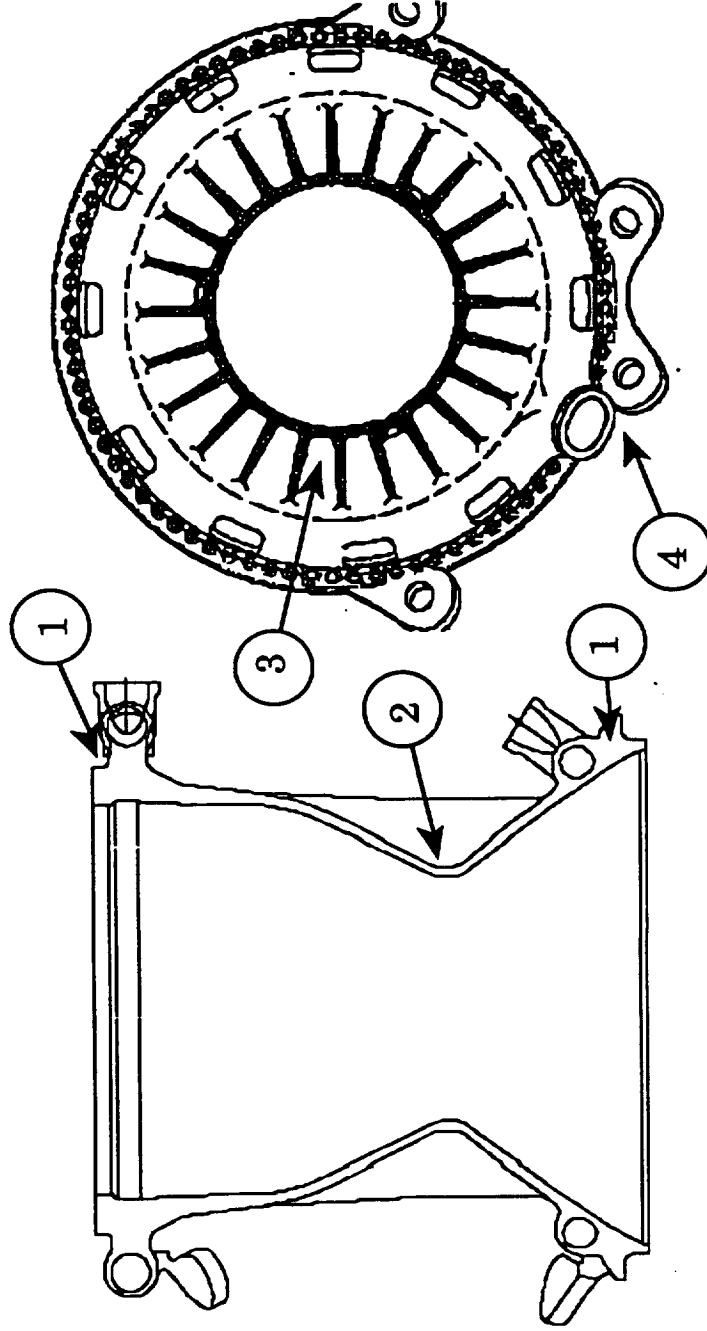


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# SPECIFIC CONCERNS



1. THICK SECTIONS - FEED DISTANCE
2. SMALL DIAMETER THROAT - FEED DIRECTION, CONTACT STYLE
3. RIBS - CERAMIC BRIDGING, ABILITY TO XRAY
4. LINK MOUNTS/BOSSES - END EFFECT, HOT SPOTS @ INLET

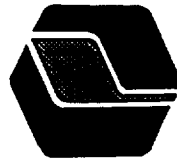


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# DEVELOPMENT FEEDBACK

- NON-DESTRUCTIVE TESTING
- PRE-HIP GATE REMOVAL
- SECTIONING PRIOR TO HIP
- CHEMICAL MILLING



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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

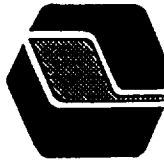
## NDT ENGINEERING

- NDT METHODS

X-RAY RADIOGRAPHY

FLUORESCENT PENETRANT

VISUAL INSPECTION



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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

## X-RAY RADIOGRAPHY

- EQUIPMENT
- FILM
- PERSONNEL



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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

- X-RAY RADIOGRAPHY



C-2

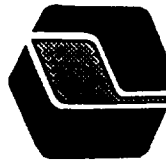
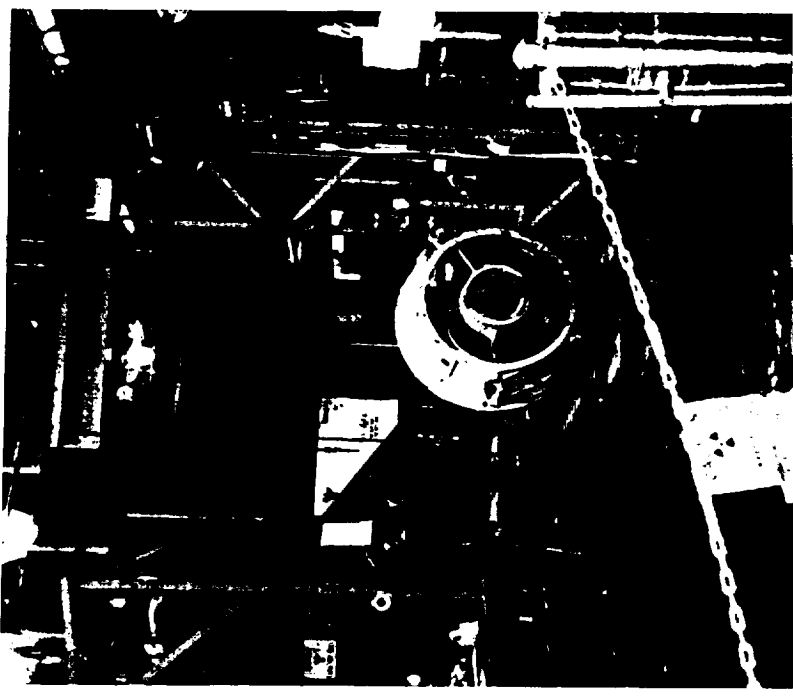
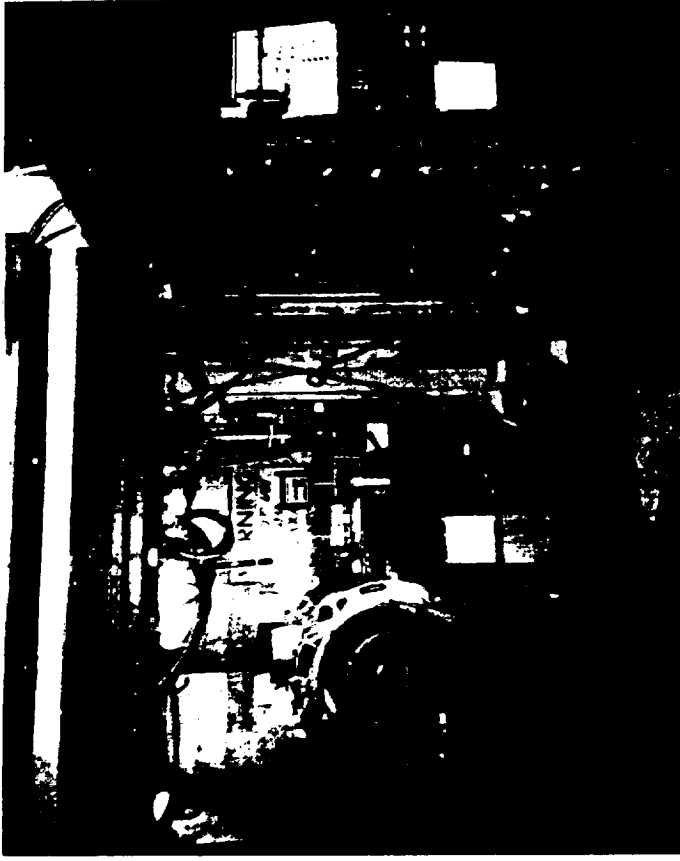


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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

- X-RAY RADIOGRAPHY



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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

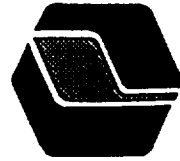
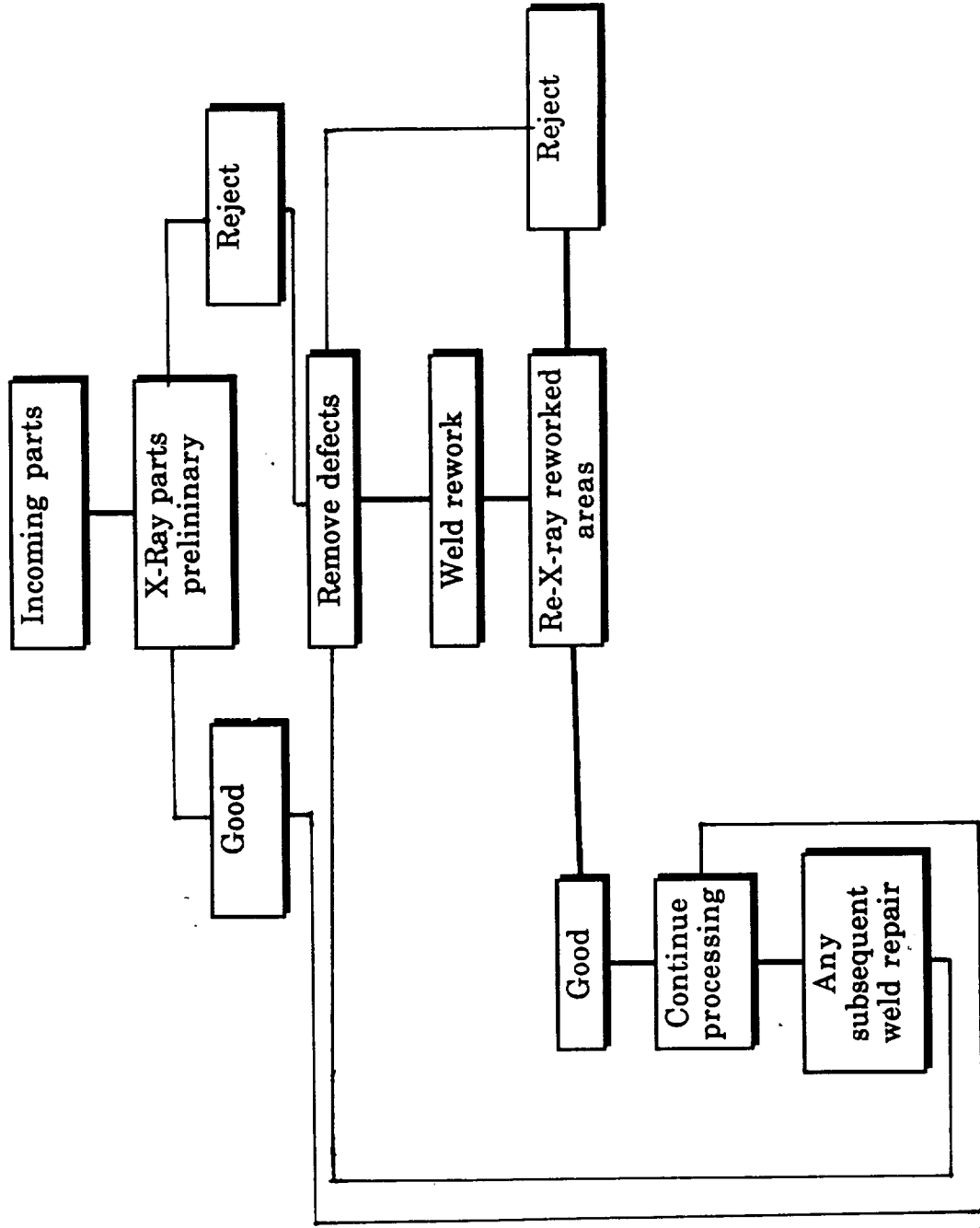
- X-RAY RADIOGRAPHY



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# FLOW DIAGRAM FOR THE X-RAY PROCESS



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# **PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT**

## **NDT PROBLEMS**

### **X-RAY RADIOGRAPHY**

- PHYSICAL SIZE**
- WEIGHT**
- CONFIGURATION**
- MATERIAL**
- THICKNESS**



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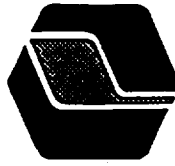
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# PRELIMINARY DESIGN REVIEW

## AMCC CASTING DEVELOPMENT

FLUORESCENT PENETRANT INSPECTION ( FPI )

- EQUIPMENT
- MATERIALS
- PERSONNEL

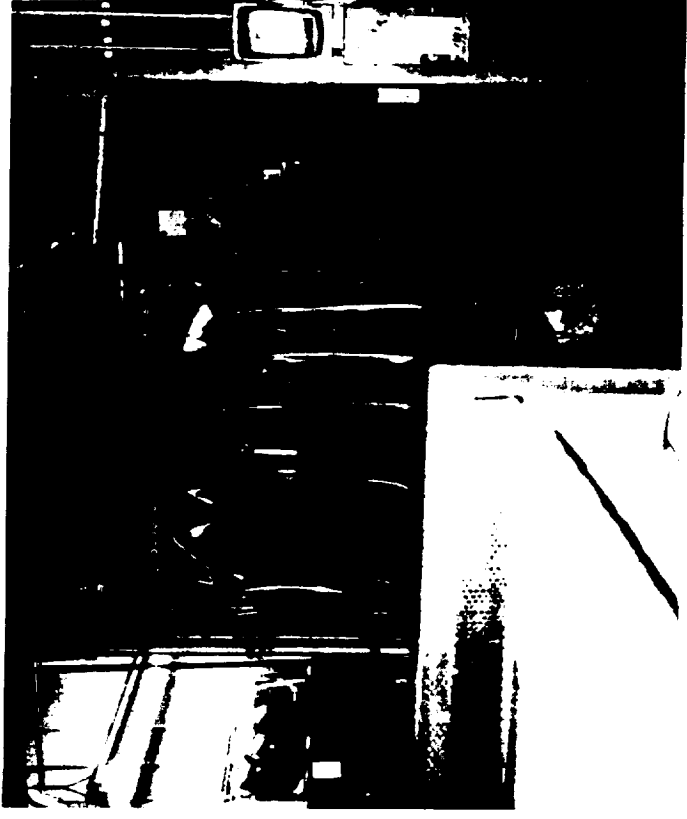


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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

- FLUORESCENT PENETRANT



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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

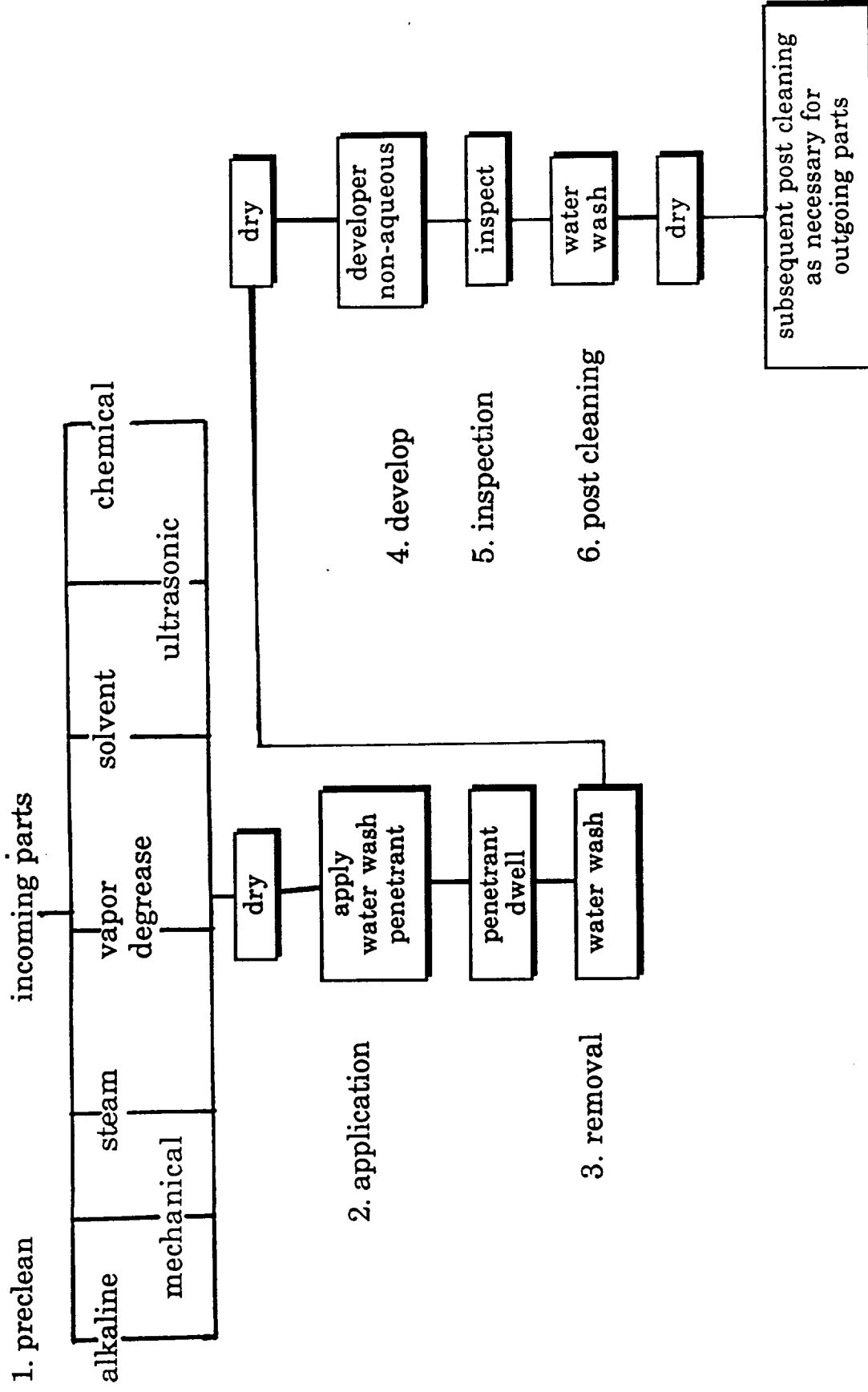
- FLUORESCENT PENETRANT



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Flow sheet showing sequence of waterwashable penetrant inspection procedure.



# **PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT**

## **NDT PROBLEMS**

## **FLUORESCENT PENETRANT**

- **PHYSICAL SIZE**
- **WEIGHT**
- **CONFIGURATION**
- **SURFACE CONDITION**



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PRELIMINARY DESIGN REVIEW  
AMCC CASTING DEVELOPMENT

VISUAL INSPECTION

- EQUIPMENT
- PERSONNEL



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# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

- VISUAL INSPECTION



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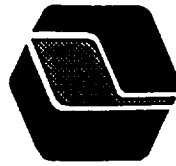


# PRELIMINARY DESIGN REVIEW AMCC CASTING DEVELOPMENT

NDT PROBLEMS

VISUAL INSPECTION

- CONFIGURATION



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# PART MANUFACTURING

- PROCESSING CONCERNS
- PROCESS OUTLINE
- INSPECTION RESULTS



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## PROCESSING CONCERNS

- HANDLING; wax patterns, molds and castings; safety, quality capacity
- MOLD MAKING/PRE-HEAT; cracks, leaks & cooling
- CASTING; process settings and choreography
- CLEANING AND FINISHING; minimize impact
- PATCH WELDING; initiate technique development
- INSPECTION METHODS; initiate technique development

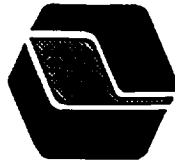


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# PROCESS OUTLINE

- GATING/FRAMING
- INVESTING/DEWAX
- CASTING
- CLEANING/FINISHING
- WELDING

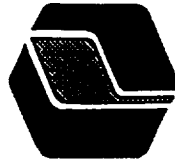


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## GATING/FRAMING

- TRIED SEVERAL GATING SYSTEMS - READY FOR GATING DOE
- FEATURES FEED WITH MINOR ASSISTANCE
- RISER SIZE/ CONTACT SHAPE LOOKS VERY CLOSE
- THROAT NEEDS GATES
- LOT 1 PROVIDED THE OPTIMAL CONTACT POINT
- LOT 3 TESTED CONTACT SHAPES & EXTERNAL COOLING
- AFT MANIFOLD CLEARANCE WORKED - NO SHELL CRACKS
- AFT MANIFOLD SPOKE GATE CLOSE - PULLED SHRINK IN CONTACT
- PROVISIONS FOR REMOVAL OF WAX - GOOD RESULTS

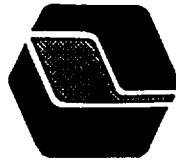


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# INVESTING/DEWAX

- DEVELOPED DIPPING PROGRAMS FOR ROBOTS
- PROCESS MODIFIED FOR LOT 2 ON TO REDUCE MOLD THICKNESS IN JACKET
- DEVELOPED TEMPERATURE MEASURING METHOD
- ENHANCED COOLING
- INSULATED GATING



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# CASTING

- USED THE VIDP MASTER CASTER FURNACE - BOTTOM POUR
- DEFINED RECIPE FOR CASTING PARTS - AUTOCASTING
- MOLD SET-UP REQUIREMENTS DEFINED
- JBK-75 ALLOY MANUFACTURE
- Nb PICKUP FROM LADLE - SPECIAL PRECAUTIONS REQUIRED
- SOME OXIDE FORMATIONS AFTER REACTIVE ADDITIONS
- PROPER AIM COMPOSITION AND MELTING TECHNIQUE  
DEFINED
- LOWERED CASTING TEMPERATURE FOR LOT 3
- USED BURNOUT MONITORING TO REDUCE RISK OF LEAKS
- ENHANCED COOLING TRIED ON LOT #3



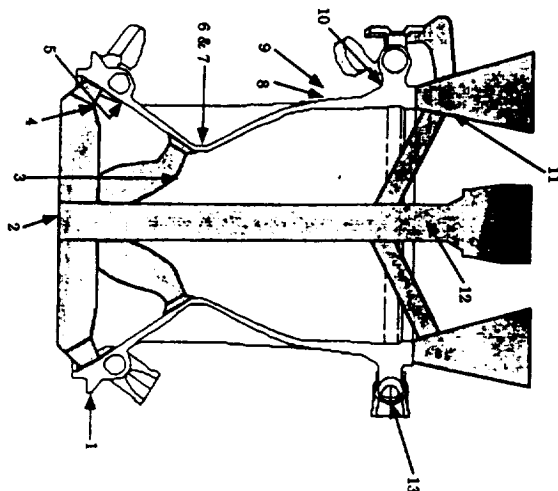
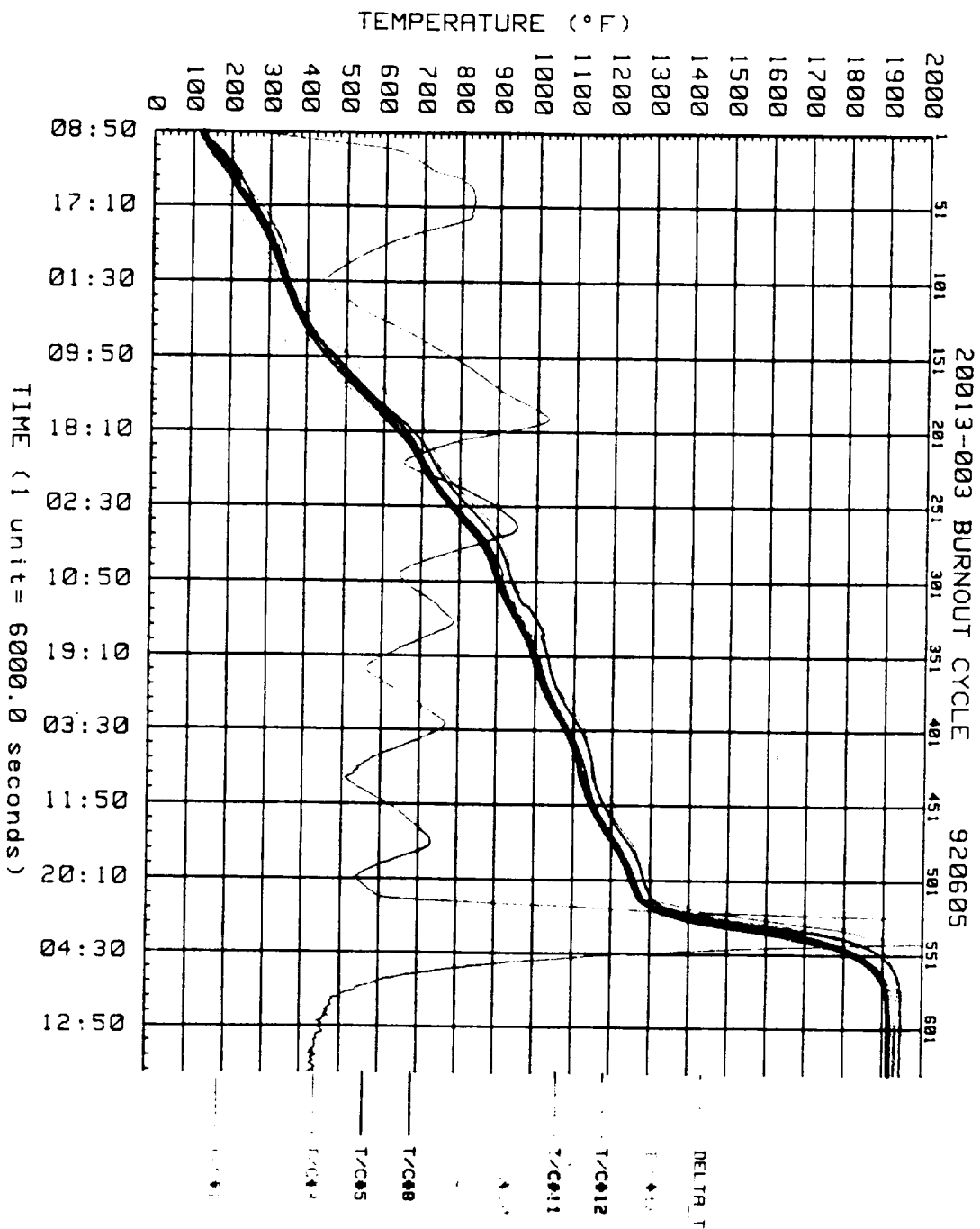
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# CLEANING/FINISHING

- MINIMIZED SHOTBLASTING
- USE HIGH PRESSURE WATER JET, KOH
- MACHINING AND GRINDING POSED NO  
SIGNIFICANT PROBLEMS

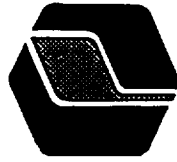


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# WELDING

- PATCH QUALITY
  - HUNG ON THE GATING FOR EARLY DEVELOPMENT
  - ONE OF TWO GATINGS WORKED BEST
  - COLUMNAR GRAIN NOTED
  - LONG TERM - PRODUCE AND CERTIFY SEPERATE FROM AMCC
- WELD QUALITY
  - USED BEST AND WORST TECHNIQUES
  - JBK WELDS GOOD - FEW INDICATIONS
  - PATCH QUALITY IMPACTED WELDING - SHRINKAGE
- DISTORTION
  - SAW IMPROVEMENT WITH EXPERIENCE
  - DEVELOPED FIXTURING - BRACES AND BACKUPS
  - 5%H2 AND 95% Ar SAVES TIME AND ALLOWS LOWER HEAT
  - WILL CONTINUE TO EVALUATE AS TECHNIQUE MATURES



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# INSPECTION RESULTS

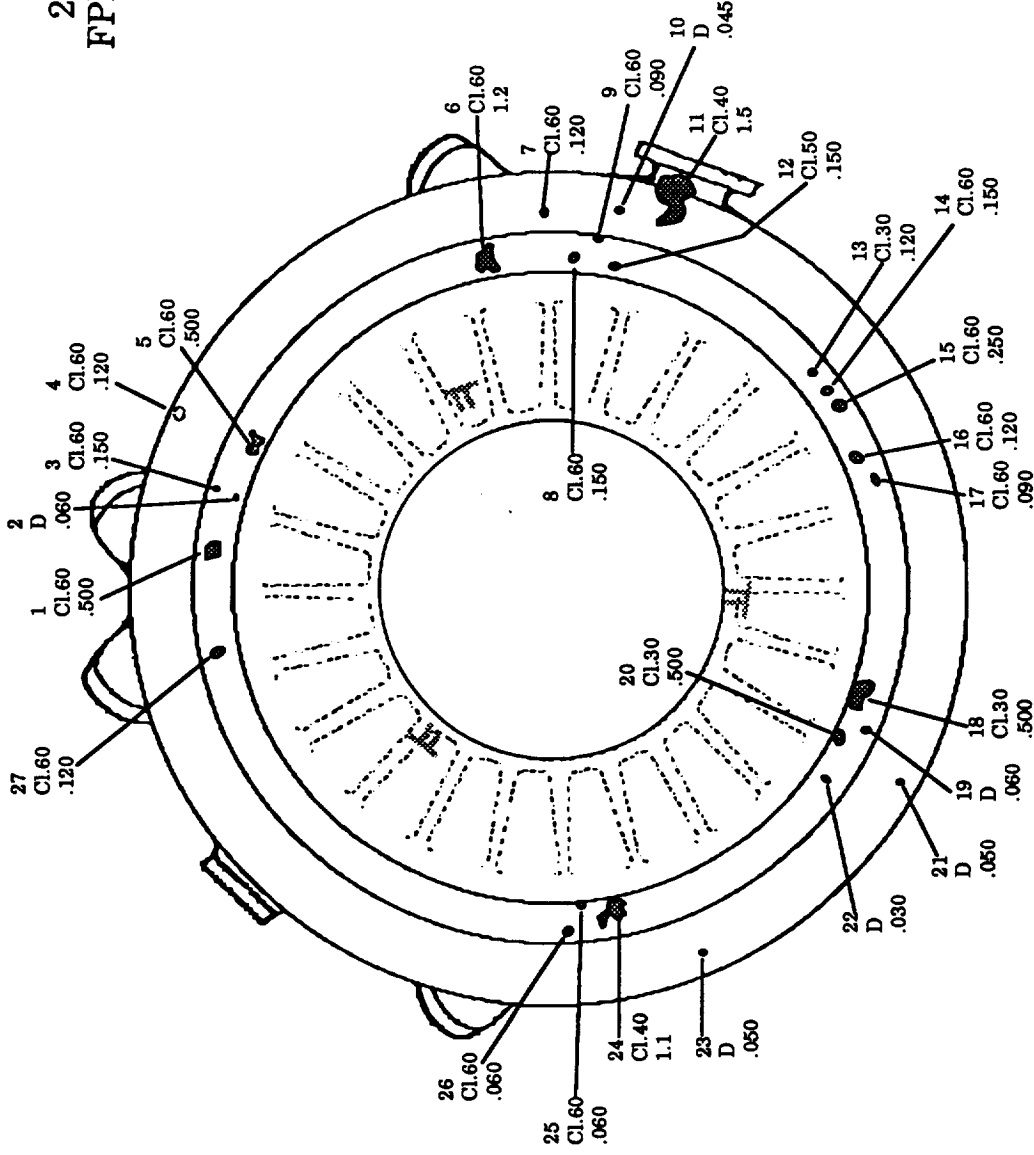
- VISUAL INSPECTION
- PRE-HIP PENETRANT
- PRE - HIP XRAY
- POST-CHEM-MILL PENETRANT
- METALLOGRAPHY



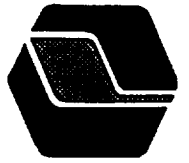
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20013 001  
FPI Post-HIP



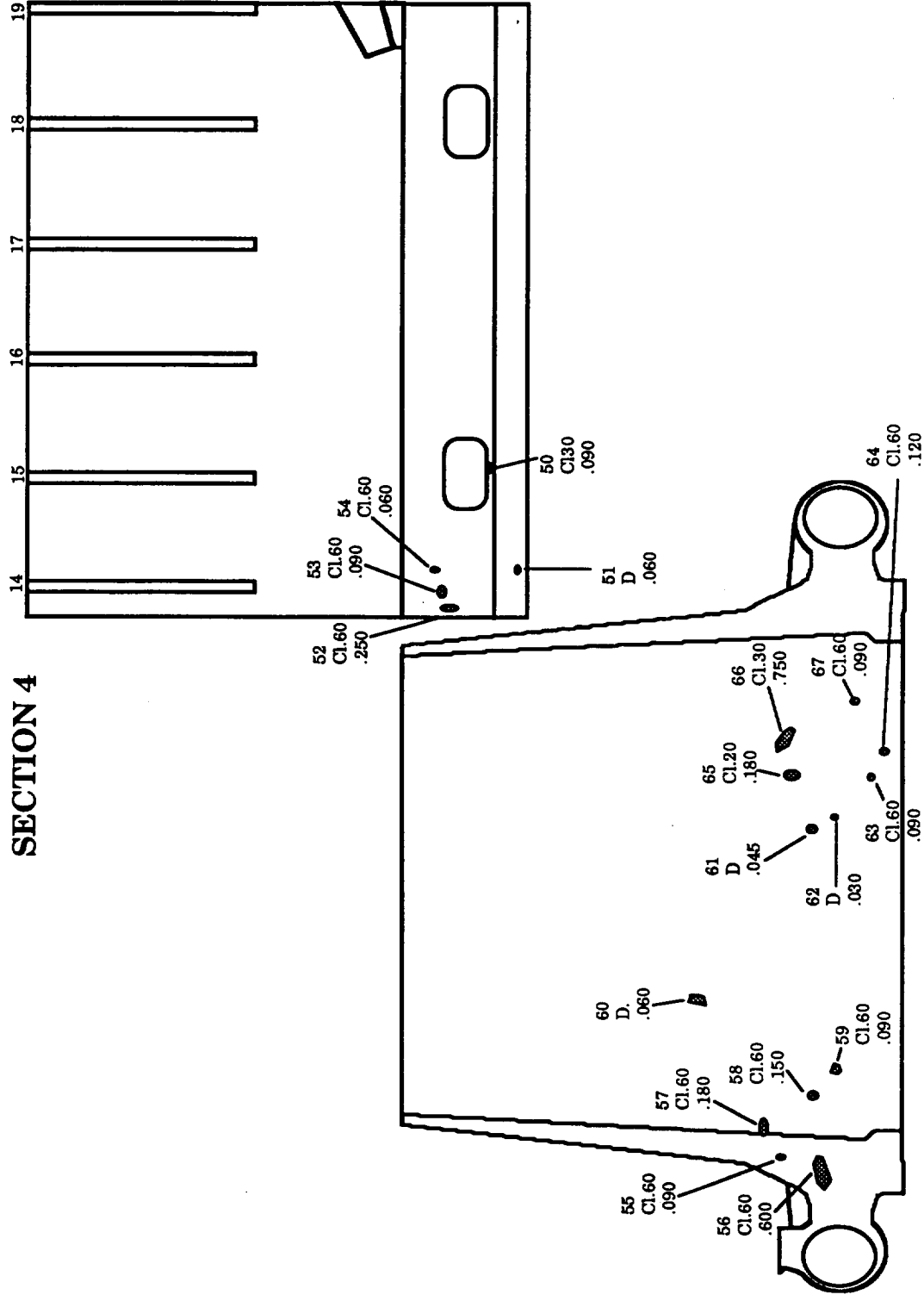
Forward Manifold looking aft



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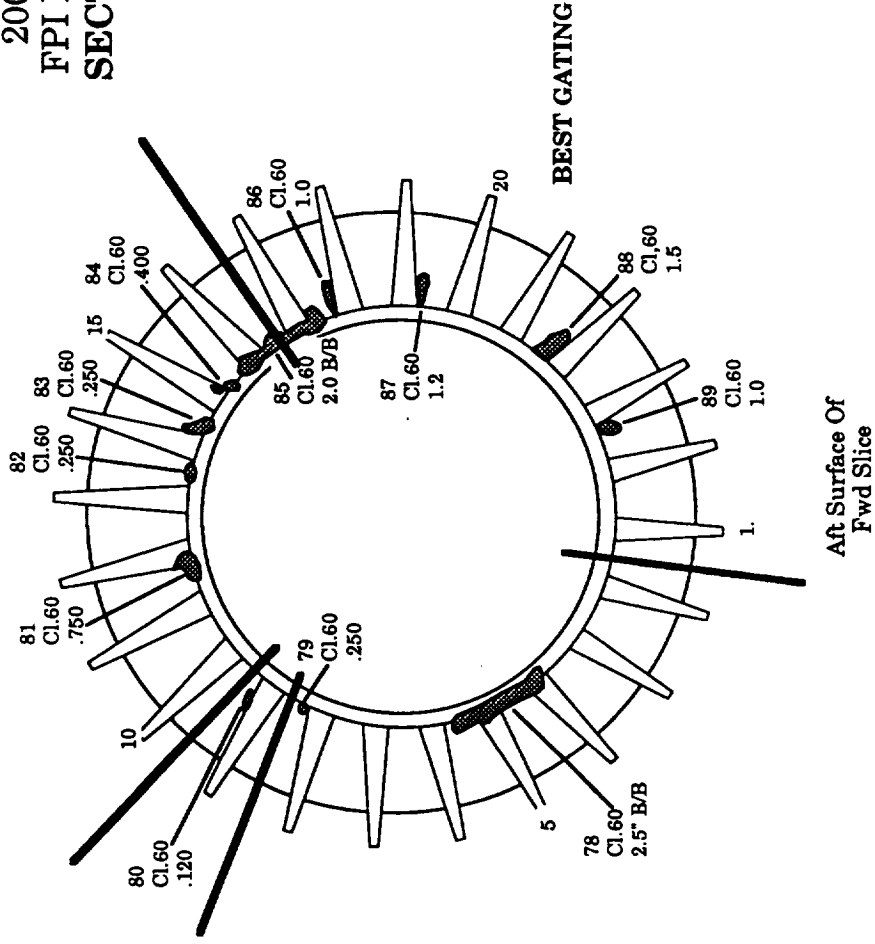
20013 001  
FPI Post-HIP  
**SECTION 4**



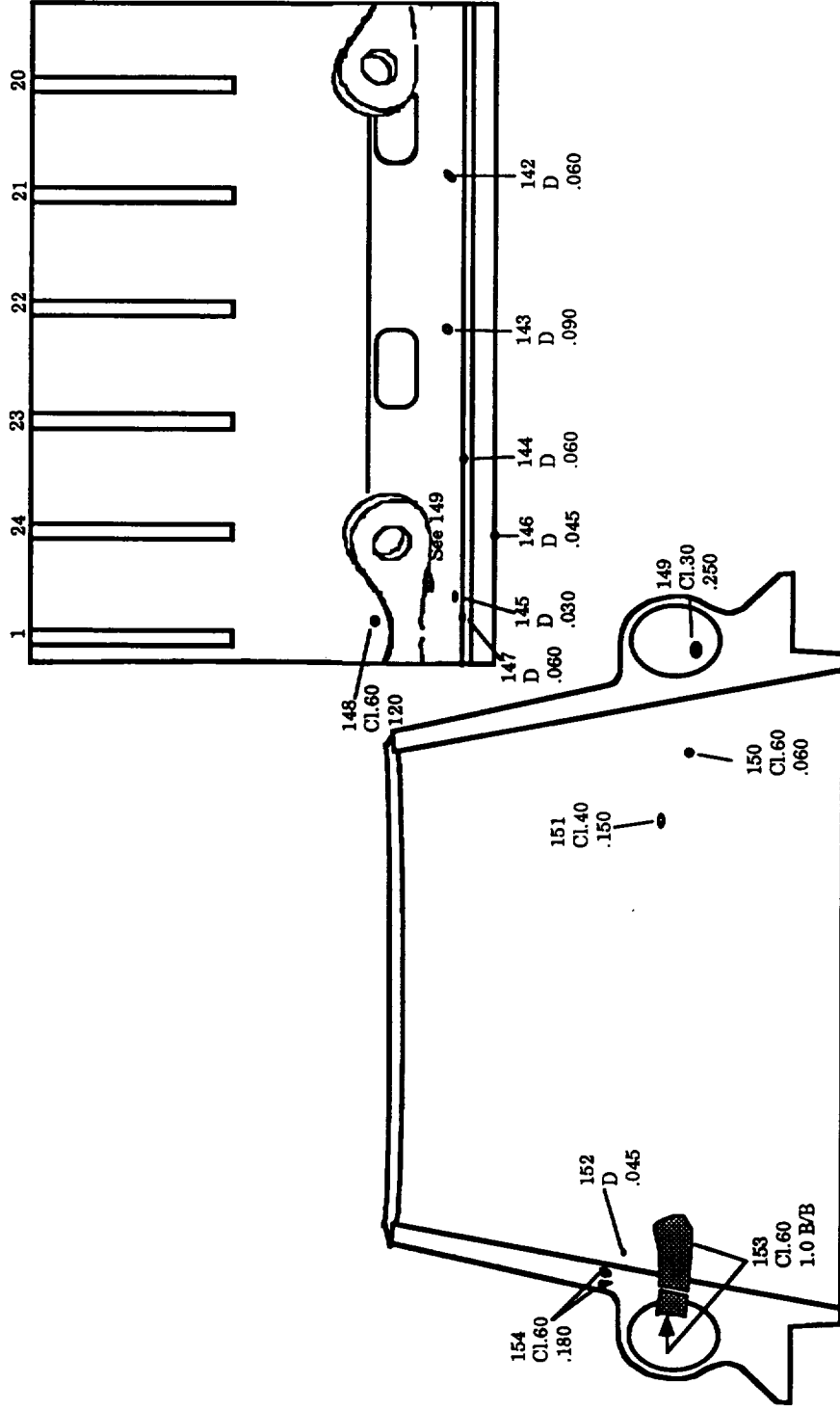
**Precision Castparts Corp.**

**NASA**

20013 001  
FPI Post-HIP  
SECTION 13



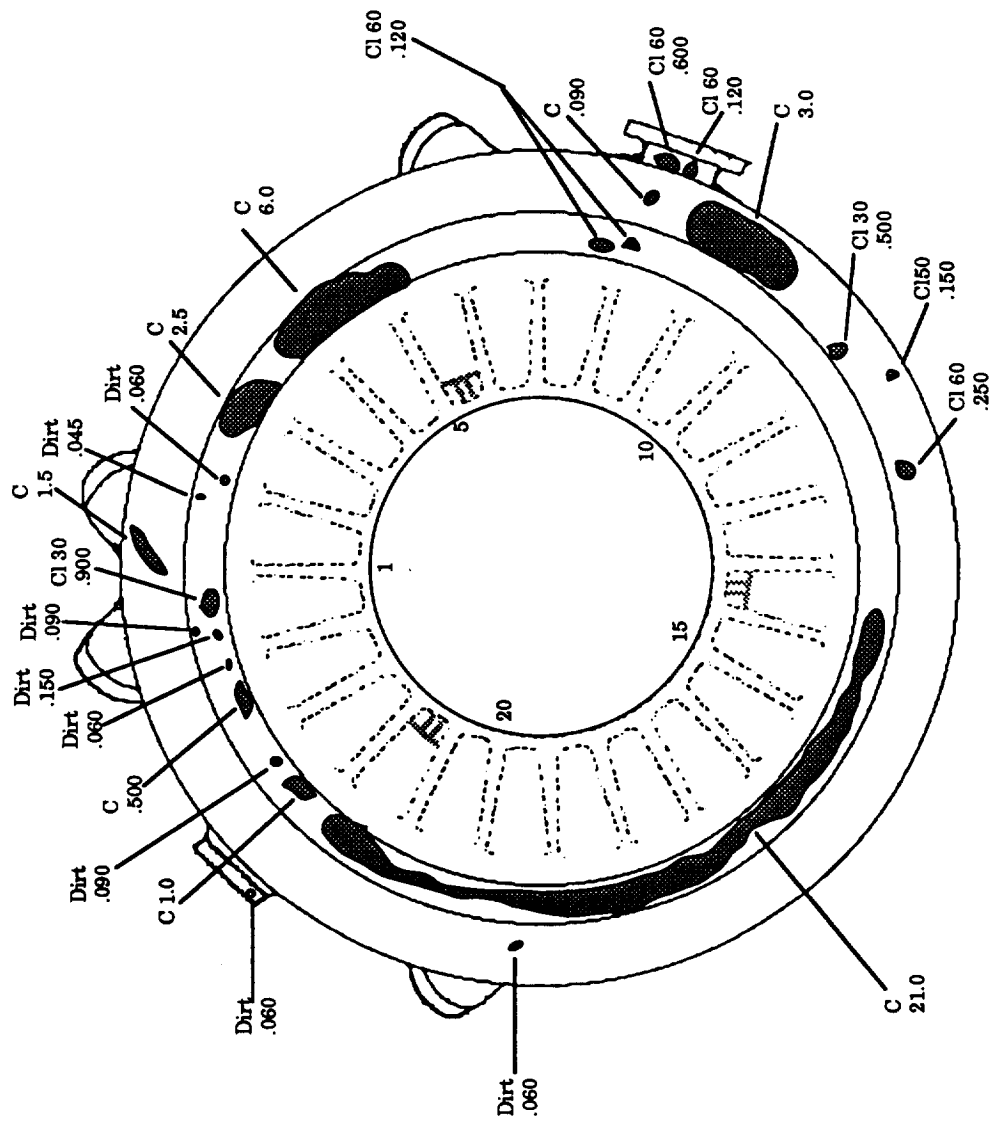
20013 001  
FPI Post-HIP  
**SECTION 1**



Precision Castparts Corp.

NASA

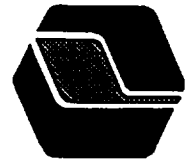
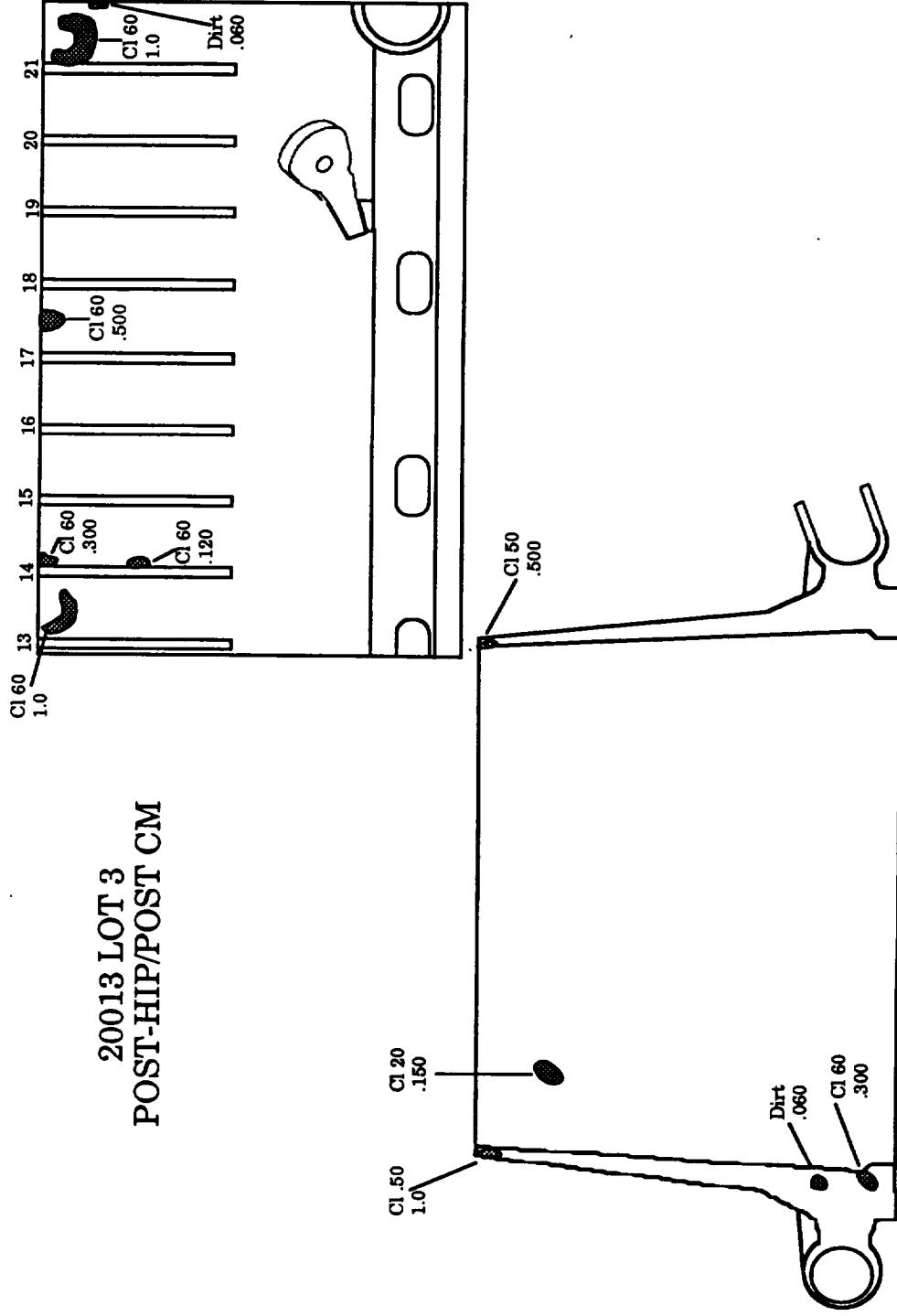
20013 LOT 3  
POST-HIP/POST CM



### Foward Manifold looking aft



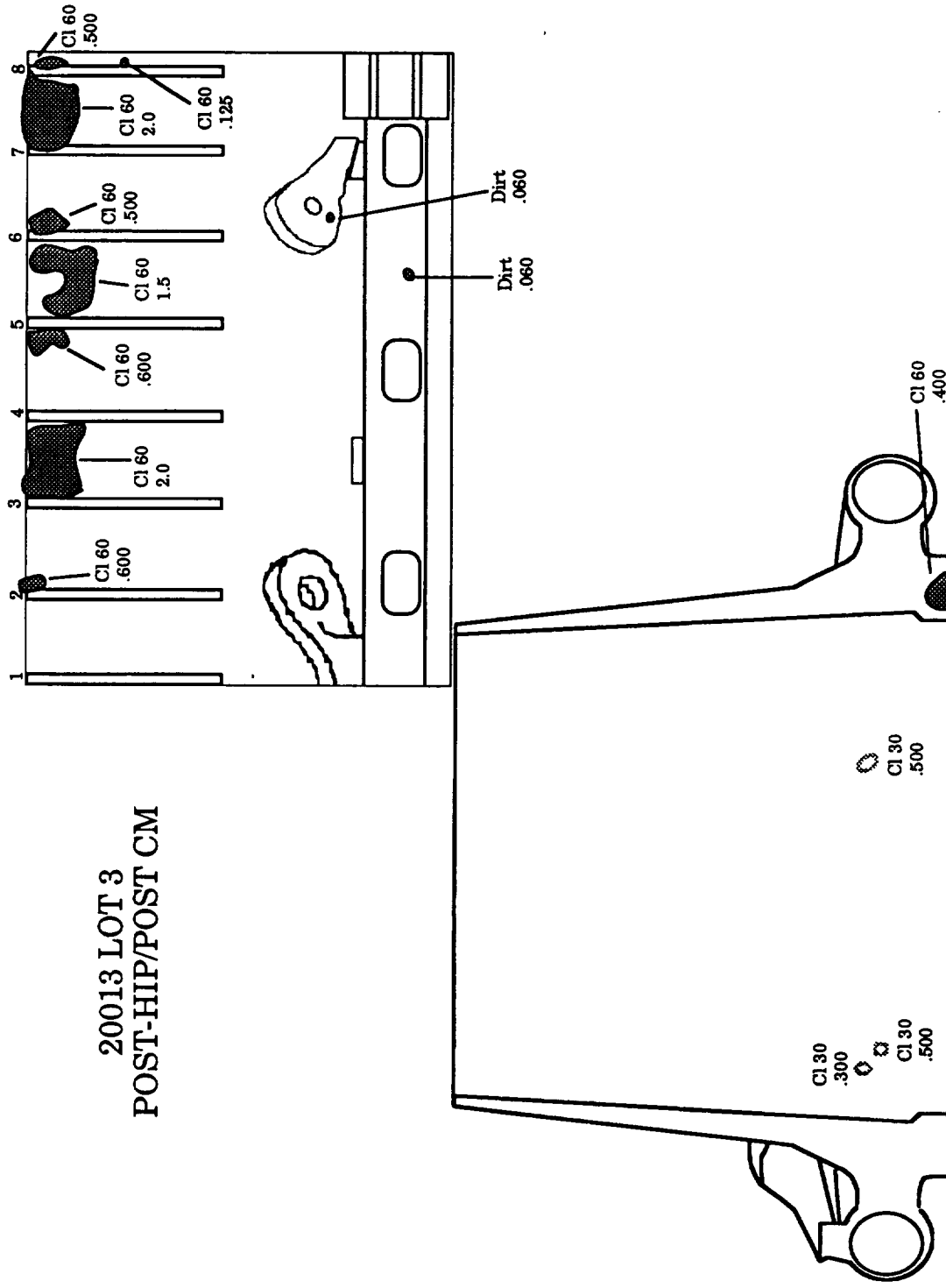
20013 LOT 3  
POST-HIP/POST CM



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# 20013 LOT 3 POST-HIP/POST CM



Precision Castparts Corp.

NASA

20013 Lot 001



Figure 28

SAMPLE 28

MAXIMUM SHRINK POROSITY .8%

Mag 10X

Mount Number P5481

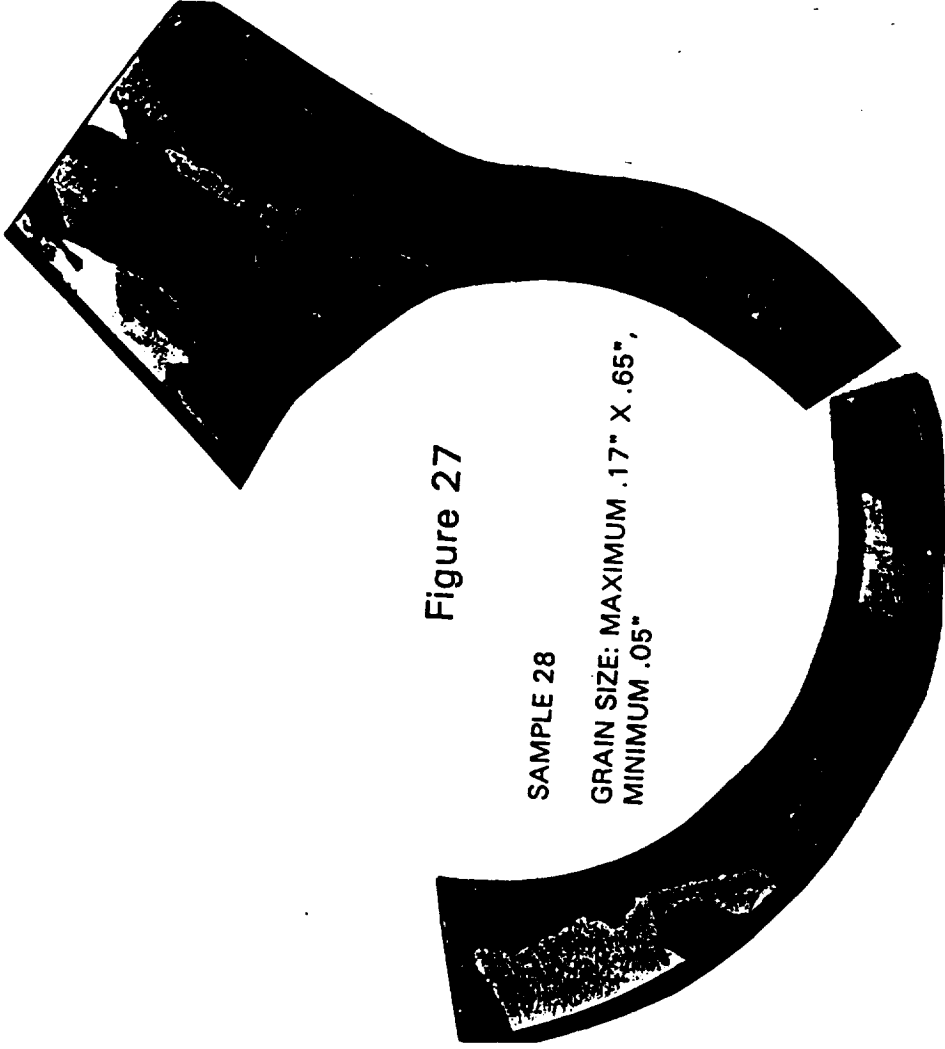


Figure 27

SAMPLE 28

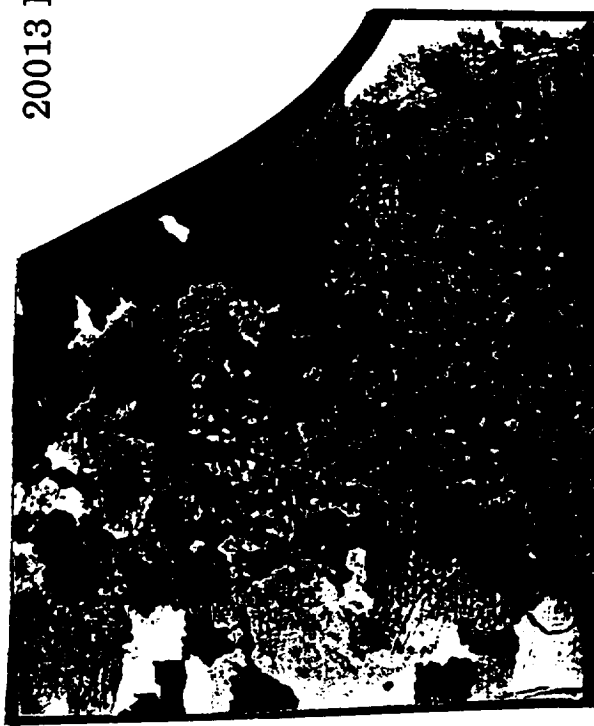
GRAIN SIZE: MAXIMUM .17" X .65",  
MINIMUM .05"



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20013 Lot 001



001-A & 001-B, MAXIMUM GRAIN: .45 X .6", MINIMUM .01"  
001-C & 001-D, MAXIMUM GRAIN: .3 X .45", MINIMUM .01"



Precision Castparts Corp.

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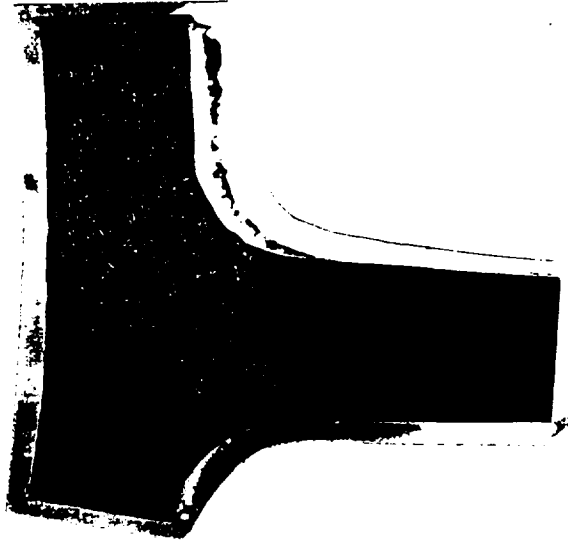


Figure 9

SAMPLE 8

MAXIMUM SHRINK POROSITY OBSERVED  
16.6%

DARKFIELD

Mag 2X X  
Mount Number P5474



Figure 8

SAMPLE 8

GRAIN SIZE: MAXIMUM .2 X .4",  
MINIMUM .01"

Mag 2X  
Mount Number P5474

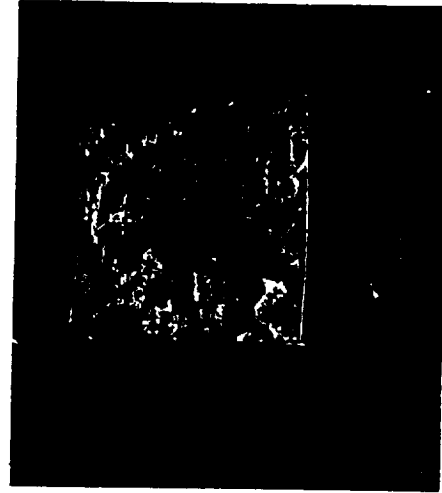


Figure 7

SAMPLE 8

Mag X  
Mount Number P5474

Metallographic Evaluation  
Part Number 20013 Lot 001



Precision Castparts Corp.

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20013 Lot 001

METALLOGRAPHIC EVALUATION

GRAIN SIZE: MAXIMUM .19 X .16" (13-3), MINIMUM .05" (13-2).  
2X



Precision Castparts Corp.

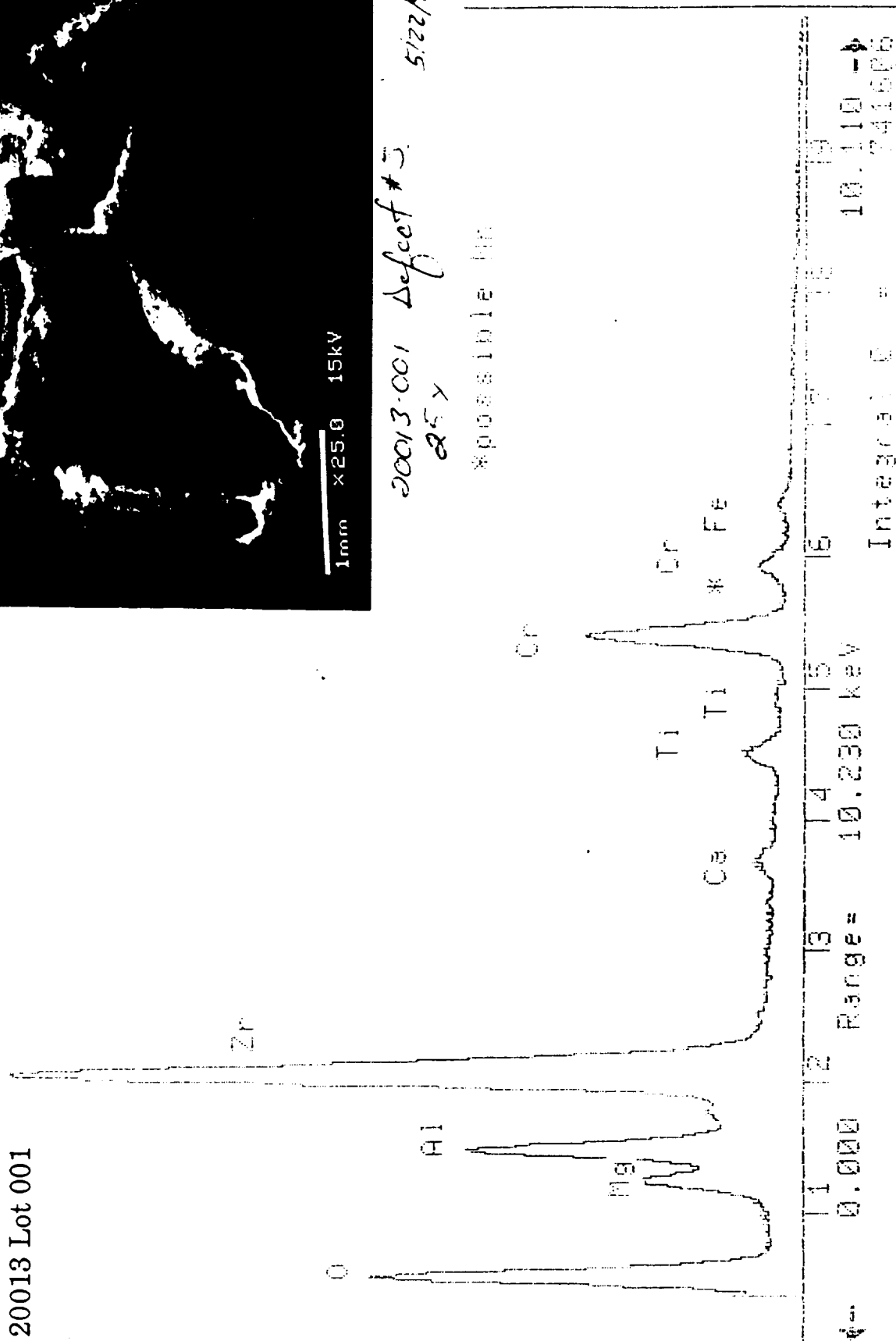
NASA

20013 Lot 001

20013-001 Defect #5  
25x

26/22:5

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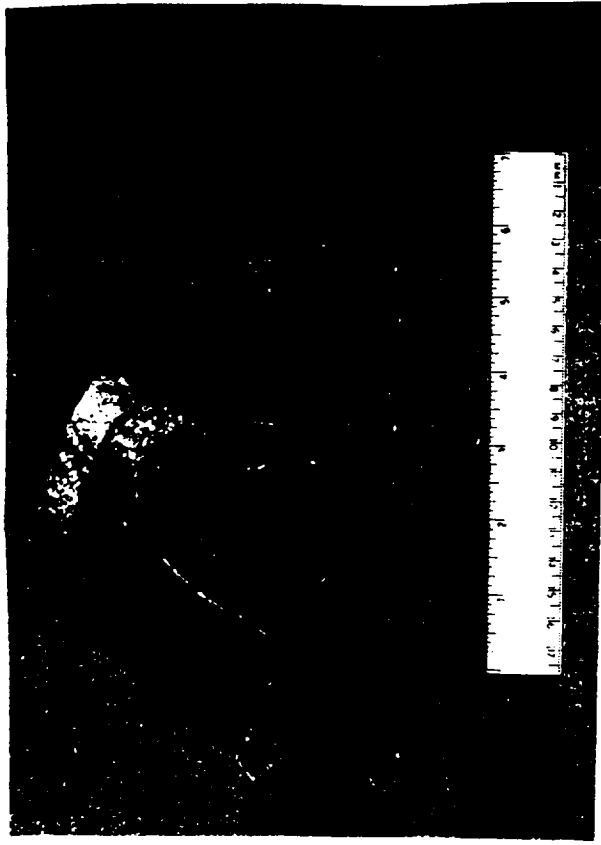


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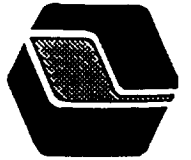
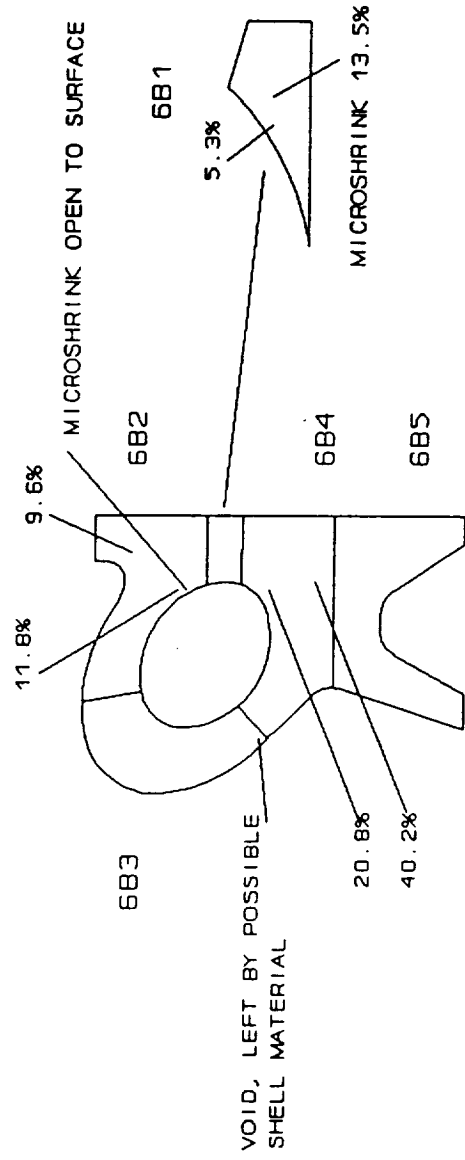
**WASA**

Metallographic Evaluation  
Part Number 20013 Lot 003

## SECTIONING DIAGRAMS AND MICROSHRINK MAPS



SECTION 6B



Precision Castparts Corp.

NASA



Metallographic Evaluation  
Part Number 20013 Lot 003



Figure 4

SECTION 6B1

MAXIMUM OBSERVED POROSITY  
IN A 40X50 MIL FIELD:

13.5%

Mag 2X

Mount Number P 6754



Figure 10

SECTION 6B4

MAXIMUM OBSERVED POROSITY  
IN A 40X50 MIL FIELD:

40.2%

Mag 2X

Mount Number P 6757



Precision Castparts Corp.

NASA

Metallographic Evaluation  
Part Number 20013 Lot 003

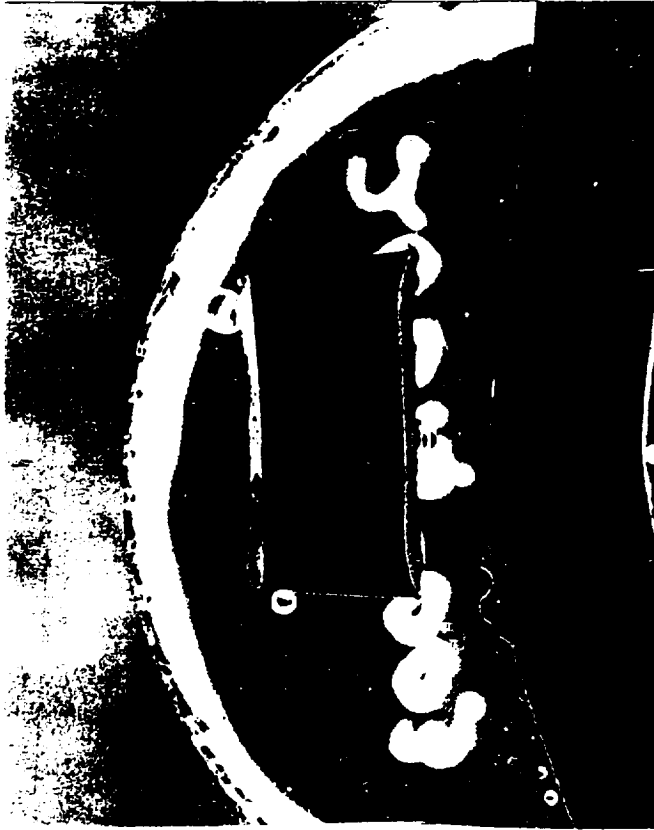


Figure 1

SECTION 4A3

MAXIMUM OBSERVED POROSITY  
IN A 40X50 MIL FIELD:

4.1%

Mag 2X

Mount Number P 6743

Figure 2



SECTION 4A3

MAXIMUM OBSERVED POROSITY  
IN A 40X50 MIL FIELD:

4.1%

Mag 10X

Mount Number P 6743



Precision Castparts Corp.

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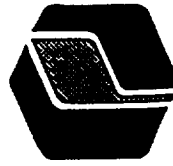
# DESIGN OF EXPERIMENT

## GATING

P/N 20013 Lots 10, 11, 12, & 13 Alloy JBK-75

### GATING DEFINITION:

The plumbing system through which liquid metal flows to fill and feed a casting during final solidification.



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# DESIGN OF EXPERIMENT

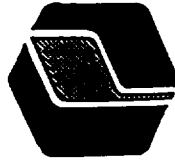
## GATING

### DESIGN OF EXPERIMENT DEFINITION:

A statistical method of exploring a product or process to study the effect of new conditions in a system.

### OBJECTIVE:

To evaluate and optimize the most effective gating scheme over a small number of castings.



**Precision Castparts Corp.**

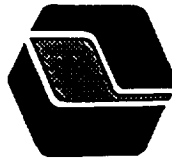
**NASA**

# DESIGN OF EXPERIMENT

## GATING

### CONSIDERATION

- Position of Pour -- Casting
- Division of Casting Configuration
- Metal Distribution
- Gate Location
- Gating Style
- Size/Shape of Gates
- Thermal Gradient Control



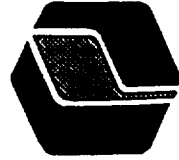
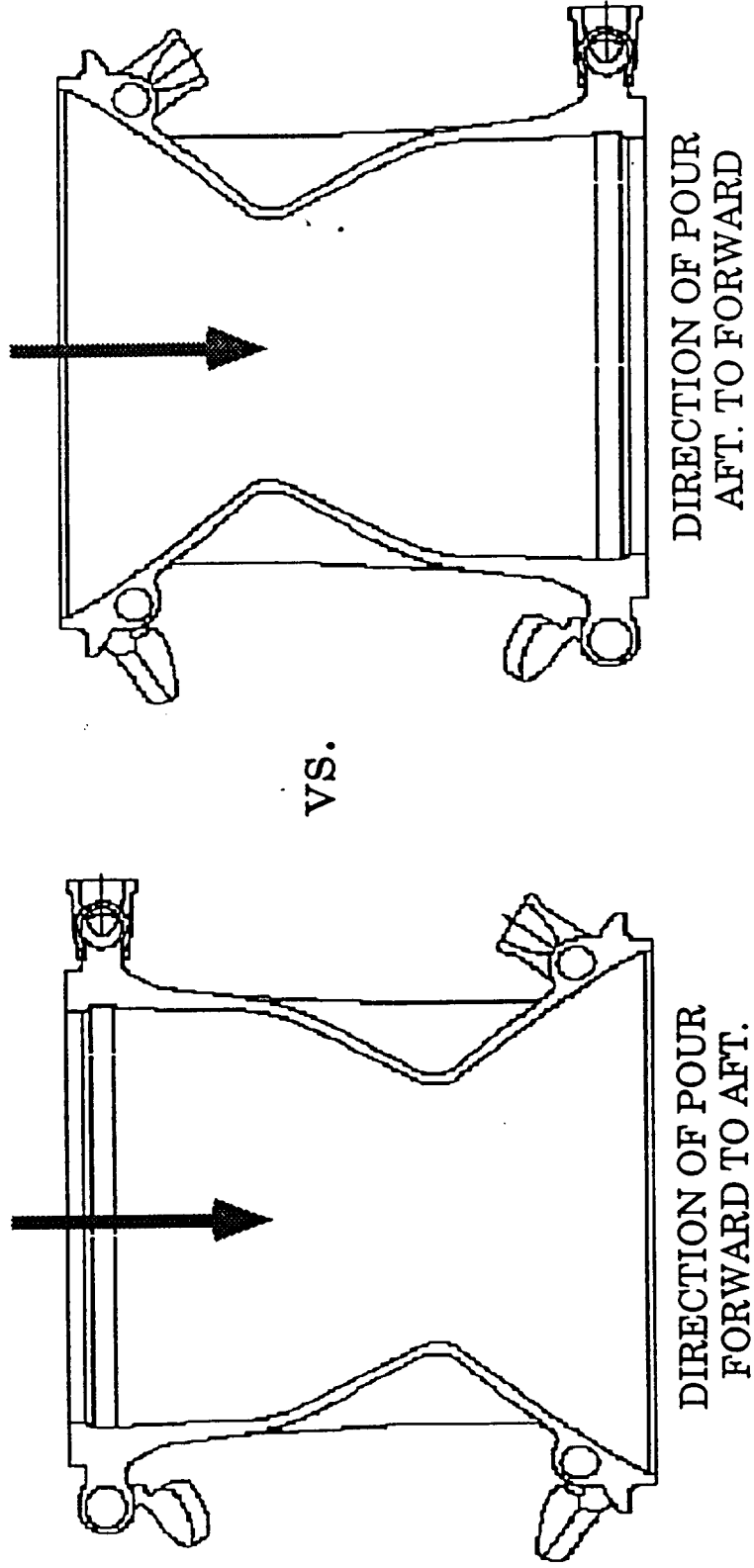
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# DESIGN OF EXPERIMENT

## GATING

### POSITION OF POUR -- CASTING



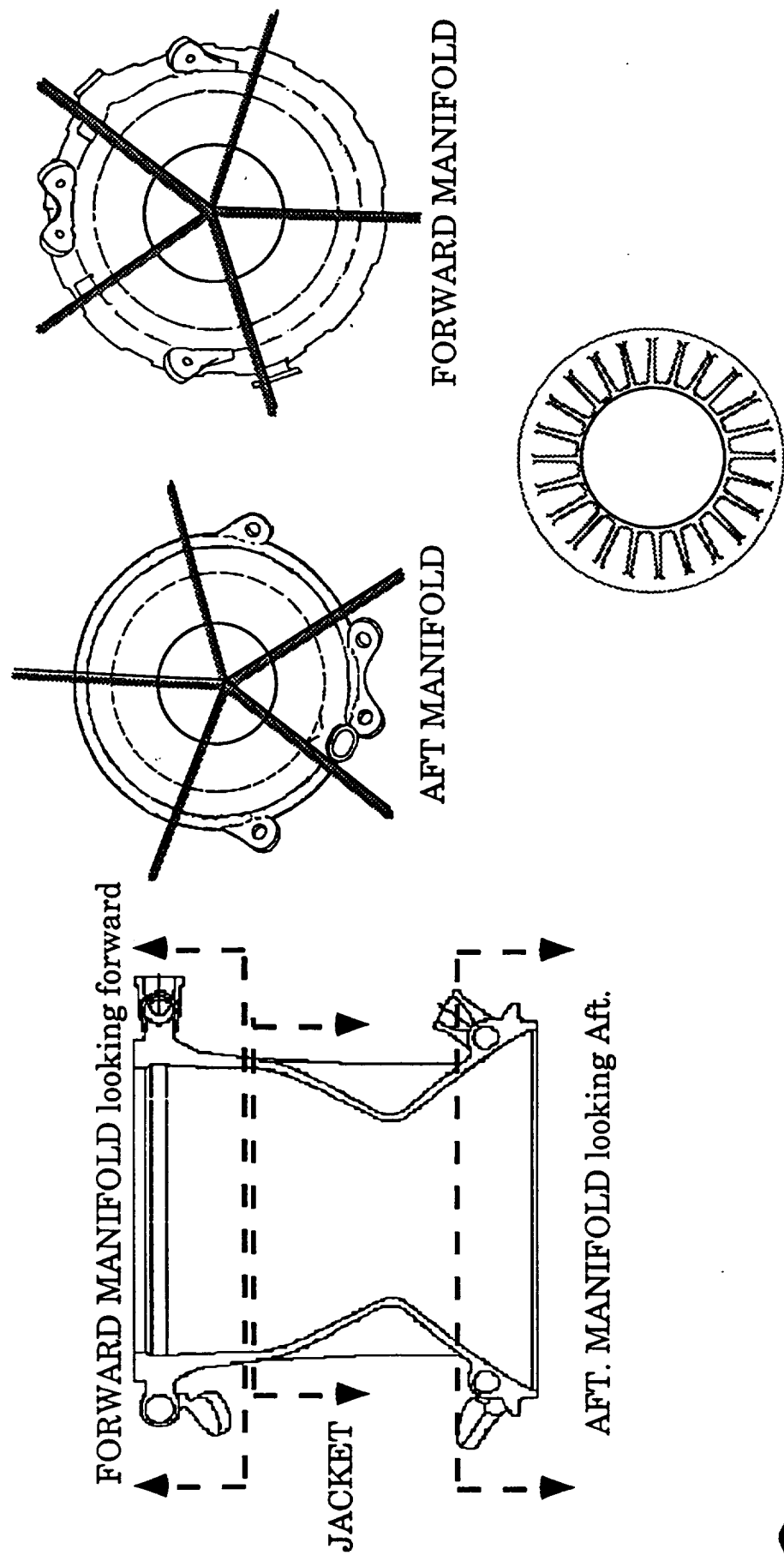
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# DESIGN OF EXPERIMENT

## GATING

### DIVISION OF CASTING CONFIGURATION



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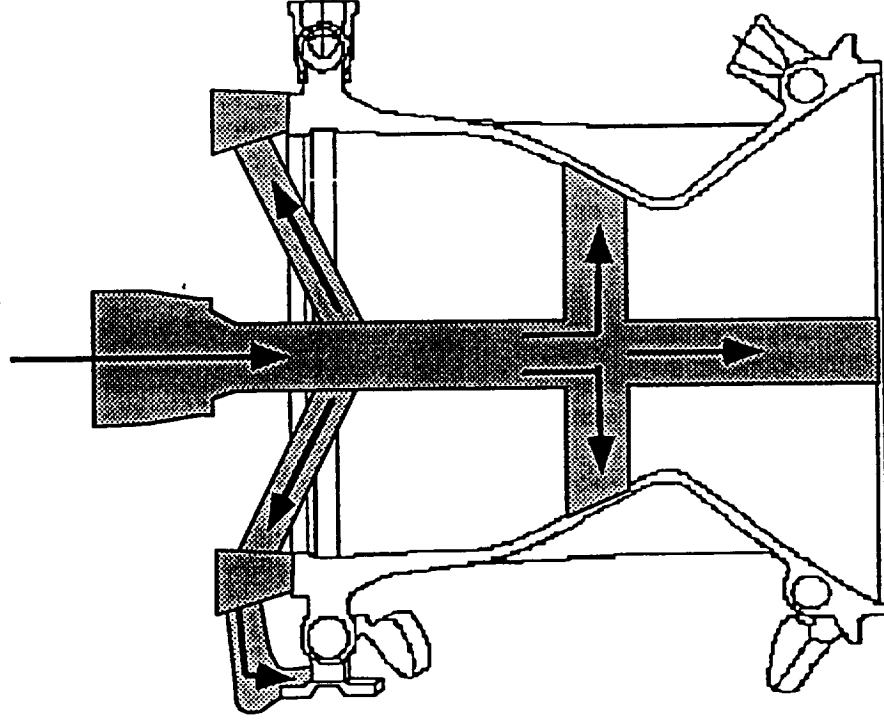
I.D. Jacket

NASA

# DESIGN OF EXPERIMENT

## GATING

### METAL DISTRIBUTION



Indicates direction  
metal flows



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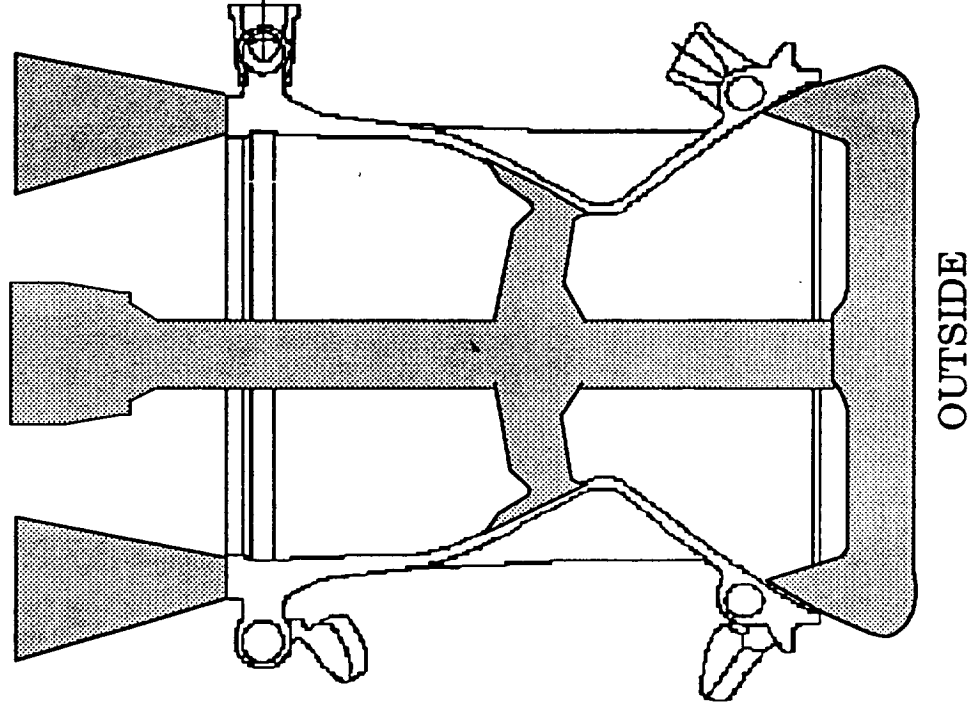
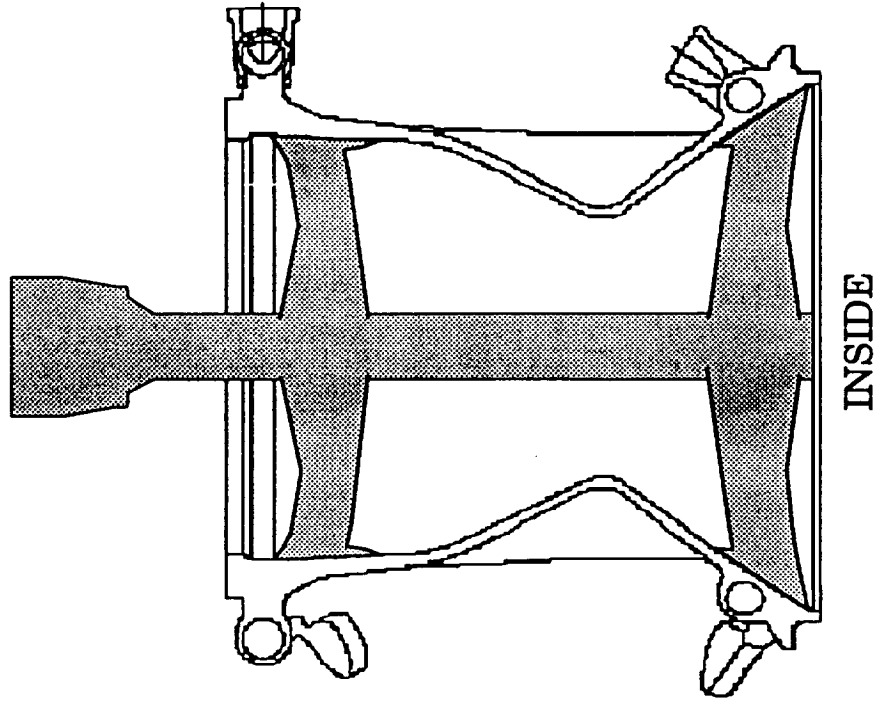
**NASA**



# DESIGN OF EXPERIMENT

## GATING

### GATE LOCATION



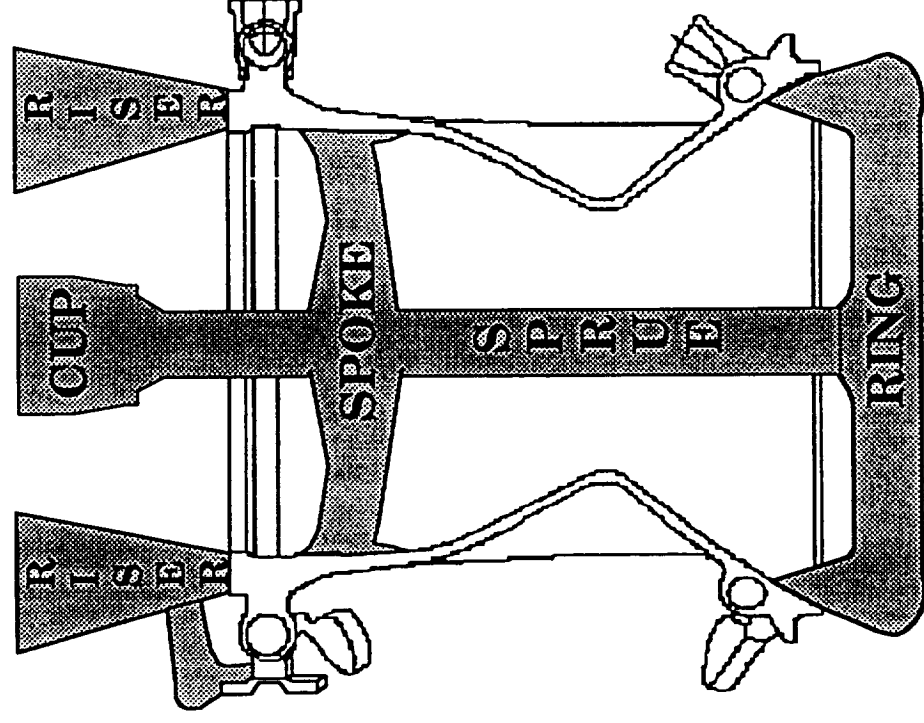
Precision Castparts Corp.

NASA

# DESIGN OF EXPERIMENT

## GATING

### GATING STYLE



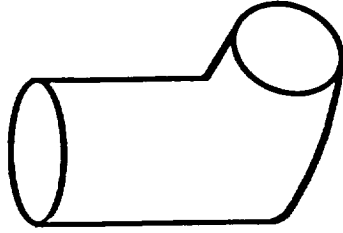
Precision Castparts Corp.

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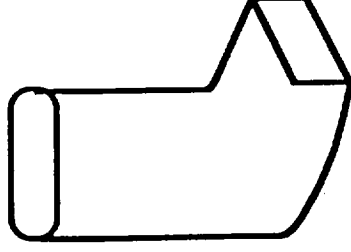
# DESIGN OF EXPERIMENT

## GATING

### SIZE/SHAPE OF GATES



ROUND



SQUARE



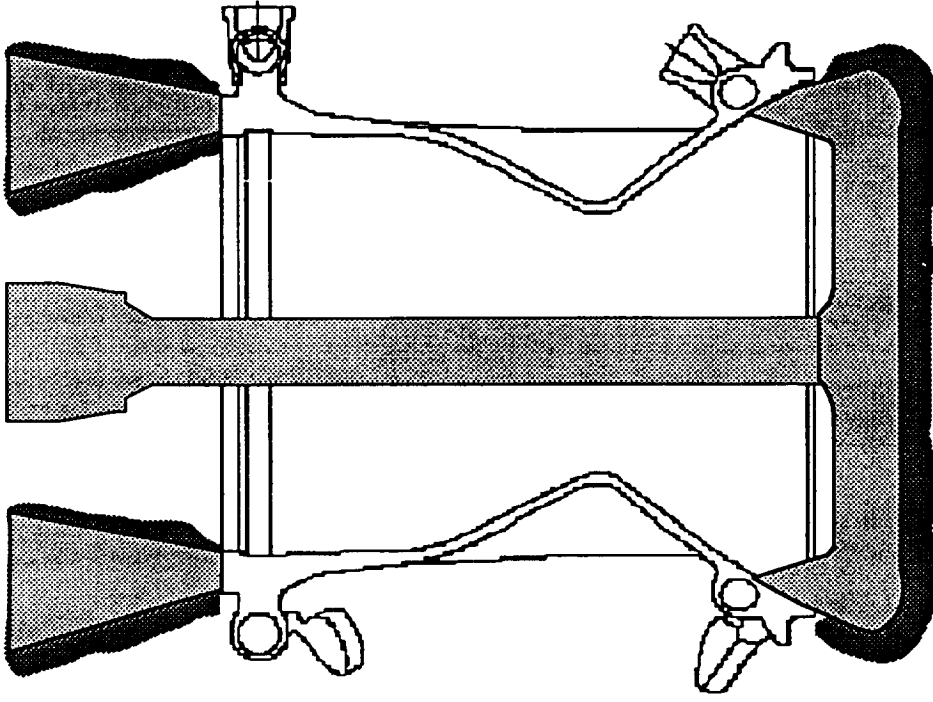
Precision Castparts Corp.

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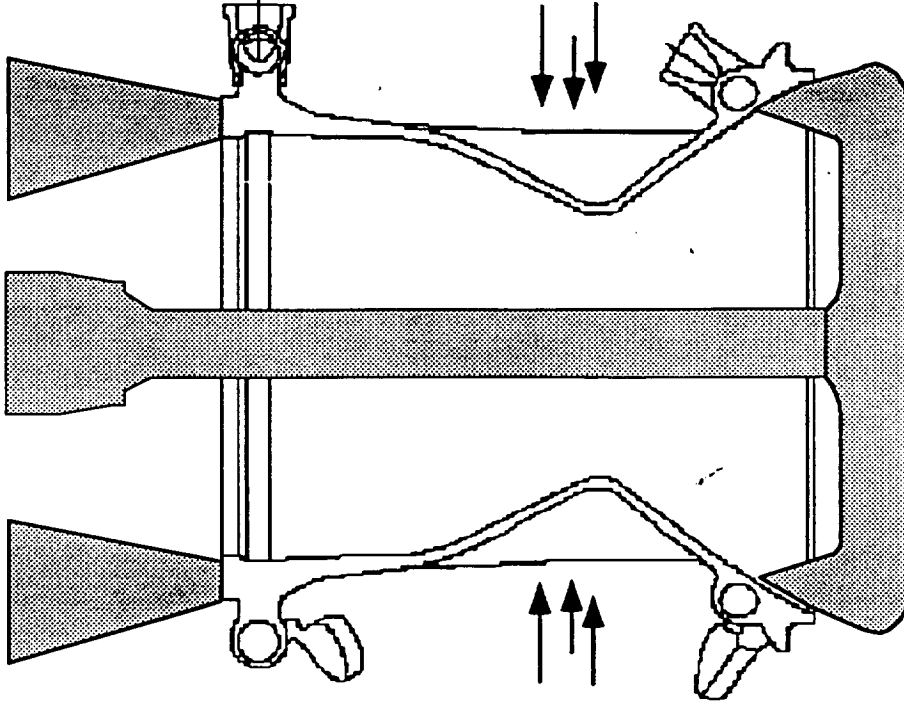
# DESIGN OF EXPERIMENT

## GATING

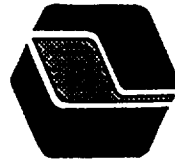
### THERMAL GRADIENT CONTROL



CONTROL HEAT LOSS INSULATION



INFLUENCE HEAT LOSS BY ALTERNATE MEANS



Precision Castparts Corp.

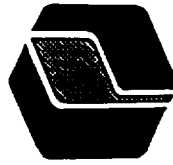
NASA

# DESIGN OF EXPERIMENT

## GATING

### METHODS TO BE USED TO EVALUATE RESULTS:

- Visual -- White Light
- Fluorescent Penetrant -- Black Light
- Radiographic -- X-Ray
- Chemical Mill -- Acid Bath
- Metallography -- Selective Section Cutup/ Mount & Polish/  
Examine



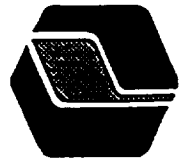
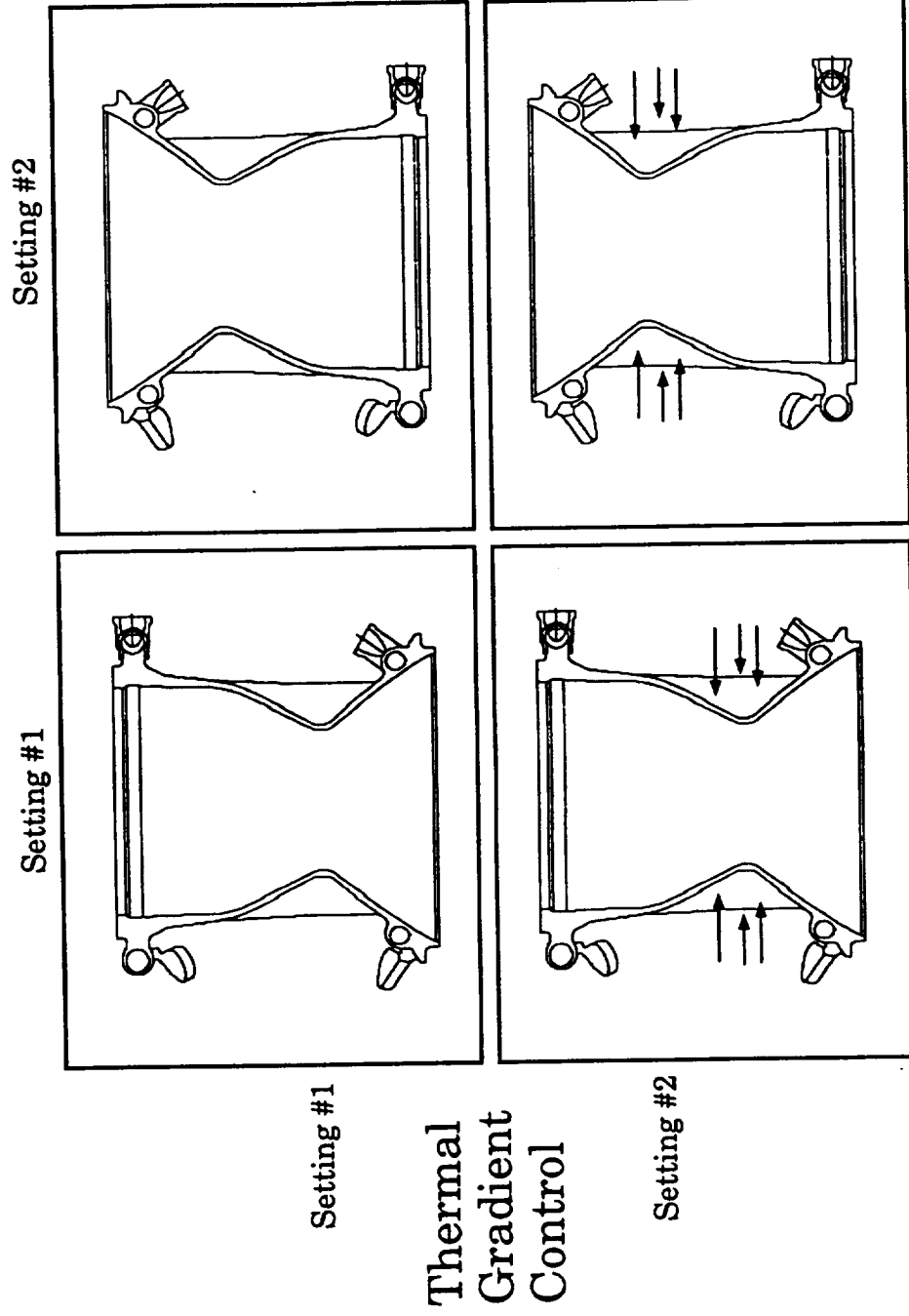
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# DESIGN OF EXPERIMENT

## GATING

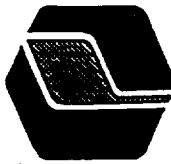
Filling



Precision Castparts Corp.

NASA

<u>CASTING</u>	<u>SEGMENT</u>	<u>LINK</u> <u>MOUNT</u>	<u>CONTACT</u>	<u>SIZE</u>	<u>LOCATION</u>
1	1	NO	STD.	SMALL	CENTER
1	2	NO	STD.	LARGE	OFF-CENTER
1	3	YES	NEW	SMALL	OFF-CENTER
1	4	YES	NEW	LARGE	CENTER
2	1	NO	NEW	LARGE	CENTER
2	2	NO	NEW	SMALL	OFF-CENTER
2	3	YES	STD.	LARGE	OFF-CENTER
2	4	YES	STD.	SMALL	CENTER
3	1	NO	NEW	LARGE	OFF-CENTER
3	2	NO	NEW	SMALL	CENTER
3	3	YES	STD.	LARGE	CENTER
3	4	YES	STD.	SMALL	OFF-CENTER
4	1	NO	STD.	SMALL	OFF-CENTER
4	2	NO	STD.	LARGE	CENTER
4	3	YES	NEW	SMALL	CENTER
4	4	YES	NEW	LARGE	OFF-CENTER



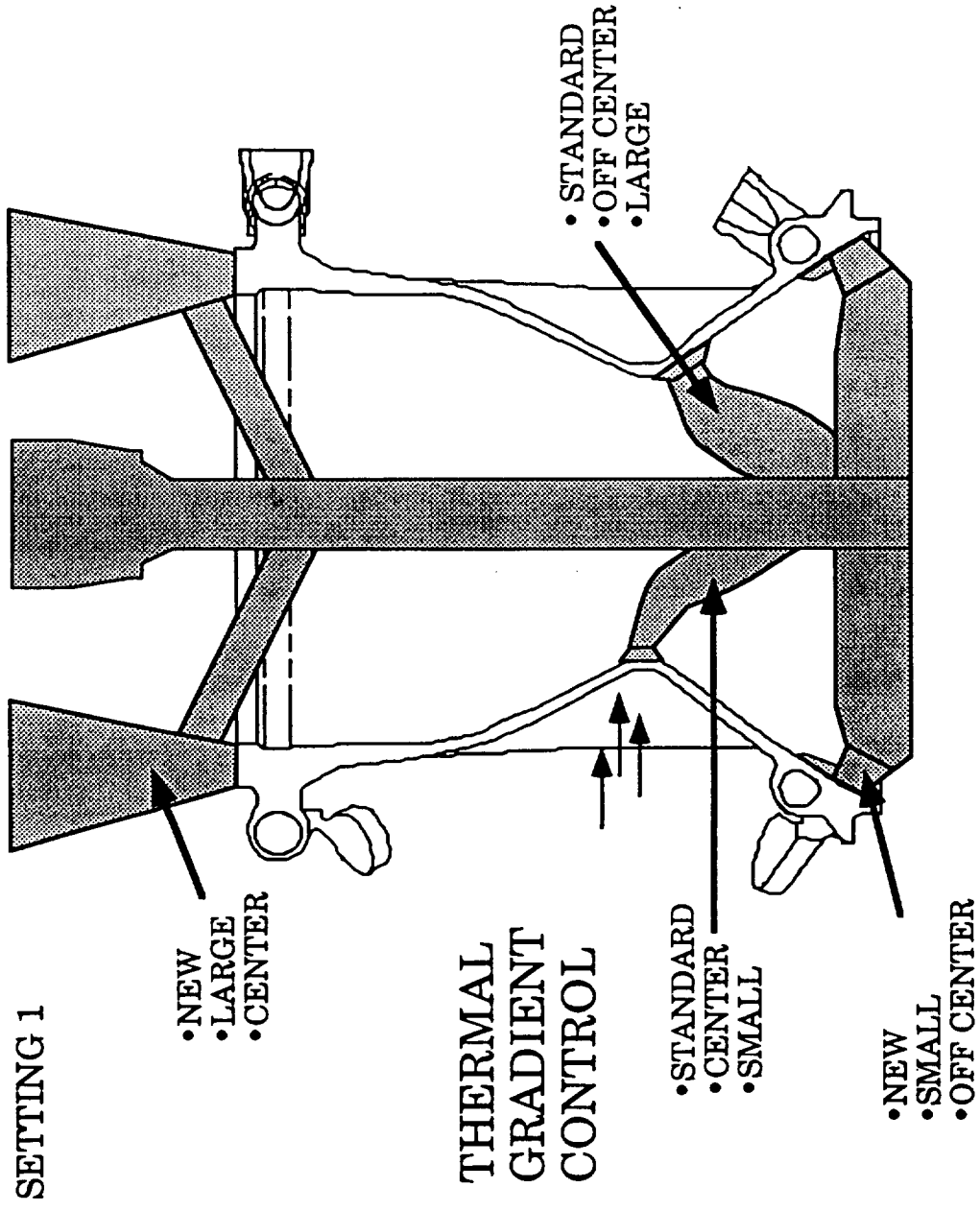
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# DESIGN OF EXPERIMENT

## GATING

### FILLING



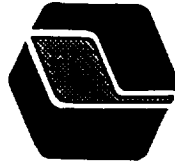
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## **QUALITY ISSUES**

- **CASTING INSPECTABILITY**
- **N D T METHODS**
- **QUALITY REQUIREMENTS**
- **SPECIAL PROCESSES**
- **QUALITY CONTROL SYSTEMS**



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# PROCESS AND QUALITY CONTROL

- MIL - Q - 9858 QUALITY PROGRAM REQUIREMENTS
- MIL - I 45208 INSPECTION SYSTEM REQUIREMENTS

## PRECISION CASTPARTS CORP.

- QUALITY CONTROL MANUAL "QCM"
- QUALITY CONTROL PROCEDURES "QCPs"
- QUALITY CONTROL INSTRUCTIONS "QCIs"
- PROCESS CONTROL PROCEDURES "PCPs"

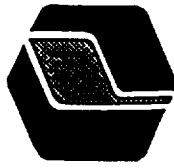


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## QUALITY REQUIREMENTS

- BLUEPRINT
- PURCHASE ORDER
- CUSTOMER SPECIFICATIONS
- INDUSTRY STANDARDS
- PCC DEVELOPED STANDARDS AND SPECIFICATIONS

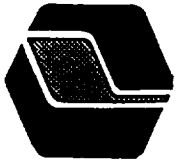


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## **SPECIAL PROCESSES**

- **HIPPING**
- **HEAT TREAT**
- **WELDING**



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**PRELIMINARY DESIGN REVIEW**  
**AMCC CASTING DEVELOPMENT**

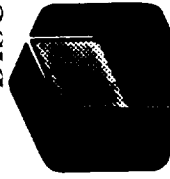
**October 12, 1993**

# PRELIMINARY DESIGN REVIEW AGENDA

## AMCC CASTING DEVELOPMENT

TUESDAY, OCTOBER 12, 1993

INTRODUCTION	STEVE WEBER	9:00 - 9:15
PART MANUFACTURING, Lots 3-7	JIM HOWCROFT	9:15 - 9:45
DIMENSIONAL ENGINEERING, Lots 3-7	JOHN DAVIS	9:45 - 10:00
	BREAK	10:00 - 10:15
NON-DESTRUCTIVE TESTING, Lots 3-7	BRUCE HAPHEY	10:15 - 10:30
GATING DOE STRATEGY, Lots 9-14	JIM HOWCROFT	10:30 - 11:30
	LUNCH	11:30 - 12:30
DIMENSIONAL RESULTS OF		
GATING DOE, Lots 9-14	JOHN DAVIS	12:30 - 1:30
GATING DOE RESULTS, Lots 9-14	JIM HOWCROFT	1:30 - 2:30
	BREAK	2:30 - 2:45
NON-DESTRUCTIVE TESTING , Lots 9-14	BRUCE HAPHEY	2:45 - 3:15
PROCESS DOE STRATEGY, Lots 17-20	BRUCE MILLER	3:15 - 3:30
DIMENSIONAL EVALUATION, Lots 17-20	PAM WRIGHT	3:30 - 3:45
SUMMARY	STEVE WEBER/JOHN BANNISTER	3:45 - 4:00
DISCUSSION & ACTION ITEMS	ALL	4:00 - ?



Precision Castparts Corp.

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# **PRECISION CASTPARTS CORP.**

**PRESENTATION TO**

**NASA**

**October 12, 1993**

**Introductions:**

## **PCC AMCC Development Team**

**Pam Wright, Engineering Technician & New Dimensional Engineer**

**John Davis, Outgoing Dimensional Engineer**

**Bruce Haphey, Quality Engineer**

**Jim Howcroft, Outgoing Part Engineer**

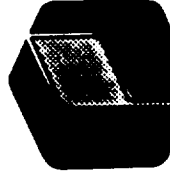
**Bruce Miller , New Part Engineer**

**Mathew Pardes, New Product Engineer**

**John Bannister, New Program Manager**

**Steve Weber, Outgoing Program Manager**

**Myrna Nutting, Account Manager**



**Precision Castparts Corp.**

**NASA**

# **PROGRAM OBJECTIVE**

---

**Produce a Structural Jacket and Coolant Manifold casting design that is:**

- More reliable**
- More predictable**
- More cost effective**

**than the wrought, machined and heavily welded design used for the current SSME Main Combustion Chamber (MCC).**



**Precision Castparts Corp.**





# **PART MANUFACTURING**

---

**JIM HOWCROFT**

- **LOTS 3 - 7**

**ALL PHASES OF INVESTMENT CASTING  
PROCESS**



**Precision Castparts Corp.**

**NASA**

# **DIMENSIONAL ENGINEERING**

---

**JOHN DAVIS**

**LOTS 3 - 7**

- **DIMENSIONAL DEVELOPMENT**
- **GENERATION OF DIMENSIONAL DATA**



**Precision Castparts Corp.**

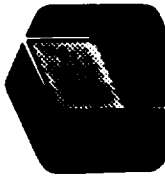
**NASA**

**LOTS 3-7**  
**NON-DESTRUCTIVE TESTING**

---

**BRUCE HAPHEY**

- **NDT PROCESS CAPABILITIES**
- **POTENTIAL PROBLEMS DEFINED**



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**CY 1991**

- P.O. RECEIVED PRODUCT SCHEDULED (2)
- BUILD HIGH QUALITY REQUESTED TOOLING (14)
  - Cad 101 Machine (10)
  - Cad 101 Machine (10)

**CY 1992**

- 11/30/92 (3)
- GATING OPTIMIZATION 4 PCEES (20)
  - FOR (3)
- IS QUALITY ACCEPTABLE? (2)
  - YES: TOOL REMOVOR (P/r dimensions & minor design changes) (6)
  - NO: BUILD GATE TOOLING (6)

**CY 1993**


- 7/6/93 (2)
- PROCESS OPTIMIZATION EXPERIMENT 6 PCEES (28)
  - FOR (3)
- 8/28/93 (24)
  - VPS support 3 PCEES

**CY 1994**

- 4/14/94 (3)
- 8/18/94 (24)
  - PLAN USABLE CASTINGS 2 PCEES (2)
- 10/2/94 (24)
  - PLAN USABLE CASTINGS 2 PCEES (2)
- 10/4/94 (22)
  - PLAN USABLE CASTINGS AS REQUIRED TO YIELD 6 PCEES TOTAL (22)

**CY 1995**

- 2/28/95 (21)
  - 8/14/94 (4)
    - SUBMIT DETAIL DATA REVIEW
  - 8/30/93 (6)
    - BUILD GATE TOOLING

- 

# VSA

# **PART ENGINEERING STRATEGY**

---

**JIM HOWCROFT**

- **STRATEGY FOR GATING DOE LOTS 9, 10, 12 & 14**
- **HOW LESSONS LEARNED FROM DOE WILL BE APPLIED TO FUTURE PARTS**



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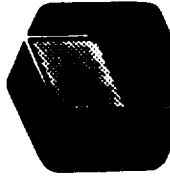
# **DIMENSIONAL RESULTS OF GATING DOE**

**Lots 9 - 14**

---

**JOHN DAVIS**

- **Gating DOE variations did not hurt Dimensional integrity of part.**
- **One piece tool for jacket would tighten down spread caused by assembly.**



**Precision Castparts Corp.**

**NASA**

# **METALLURGICAL RESULTS OF GATING DOE**

**Lots 9 - 14**

---

**JIM HOWCROFT**

- **DOE results clearly define best combination of TGC and gating.**
- **Quality of parts resulting from Gating DOE will meet NASA ultimate requirements.**



**Precision Castparts Corp.**

**NASA**

**LOTS 9 - 14**  
**NON-DESTRUCTIVE TESTING**

---

**BRUCE HAPHEY**

- **APPLICATION OF BASIC INSPECTION METHODS**
- **PROBLEM AREAS ADDRESSED**
- **KNOWLEDGE GAINED**

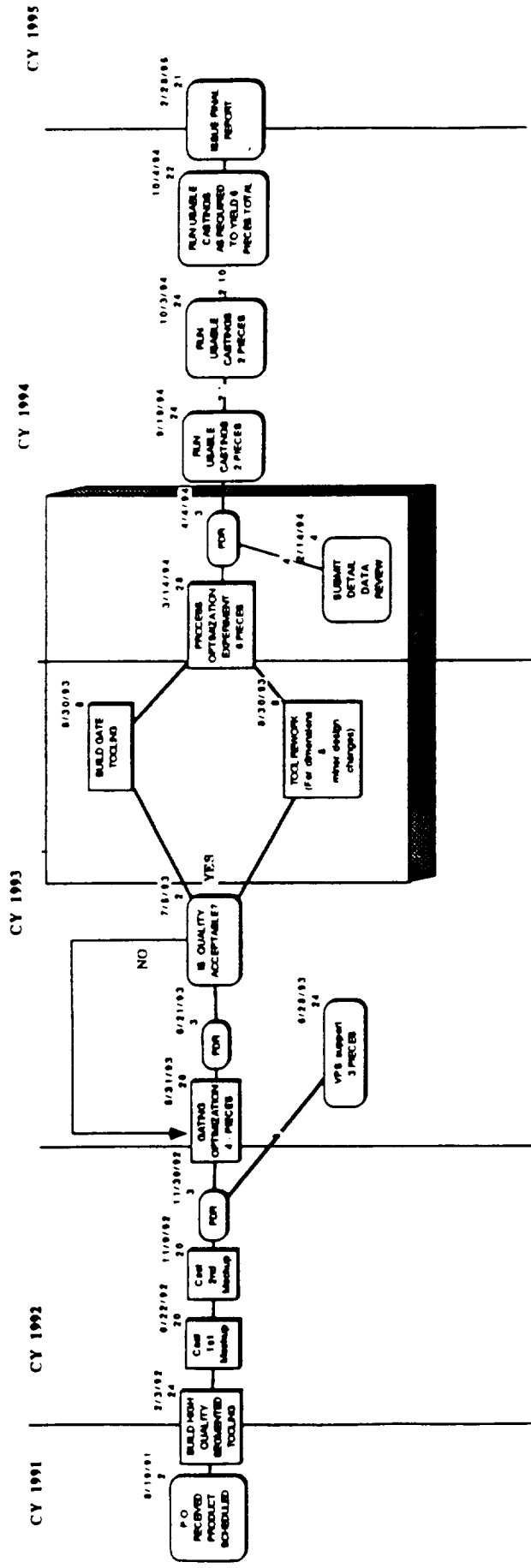


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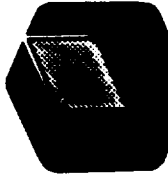
**NASA**



# DEVELOPMENT PROCESS



- ENGINEERING SAMPLES
- GATING OPTIMIZATION DOE
- **PROCESS SENSITIVITY DOE**
- PROTOTYPE PARTS - PROCESS DEMONSTRATION
- ADDITIONAL 'BEST EFFORT' CASTING



Precision Castparts Corp.

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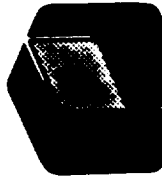
# **PROCESS DOE**

## **WHAT IS OUR STRATEGY - Lots 17 - 20**

---

**BRUCE MILLER**

- **NAIL DOWN METAL TEMPERATURES**
- **REFINE TGC APPLICATION**
- **FIND OUT HOW ROBUST OUR PROCESS IS**



**Precision Castparts Corp.**

**NASA**

# **PROCESS DOE DIMENSIONAL EVALUATION OF LOTS 17-20**

---

**PAM WRIGHT**

- **WHAT WE ARE LOOKING FOR IN THIS  
PROCESS**



**Precision Castparts Corp.**

**NASA**

# **SUMMARY**

---

**STEVE WEBER/JOHN BANNISTER**

- **PCC can make high quality parts**
- **Gating and thermal control are critical**
- **Hot Fire castings are scheduled to ship in October**
- **Process DOE will define robust process**
- **New team in place to carry program to completion**



**Precision Castparts Corp.**

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# **PART MANUFACTURING**

---

**JIM HOWCROFT**

- **LOTS 3 - 7**

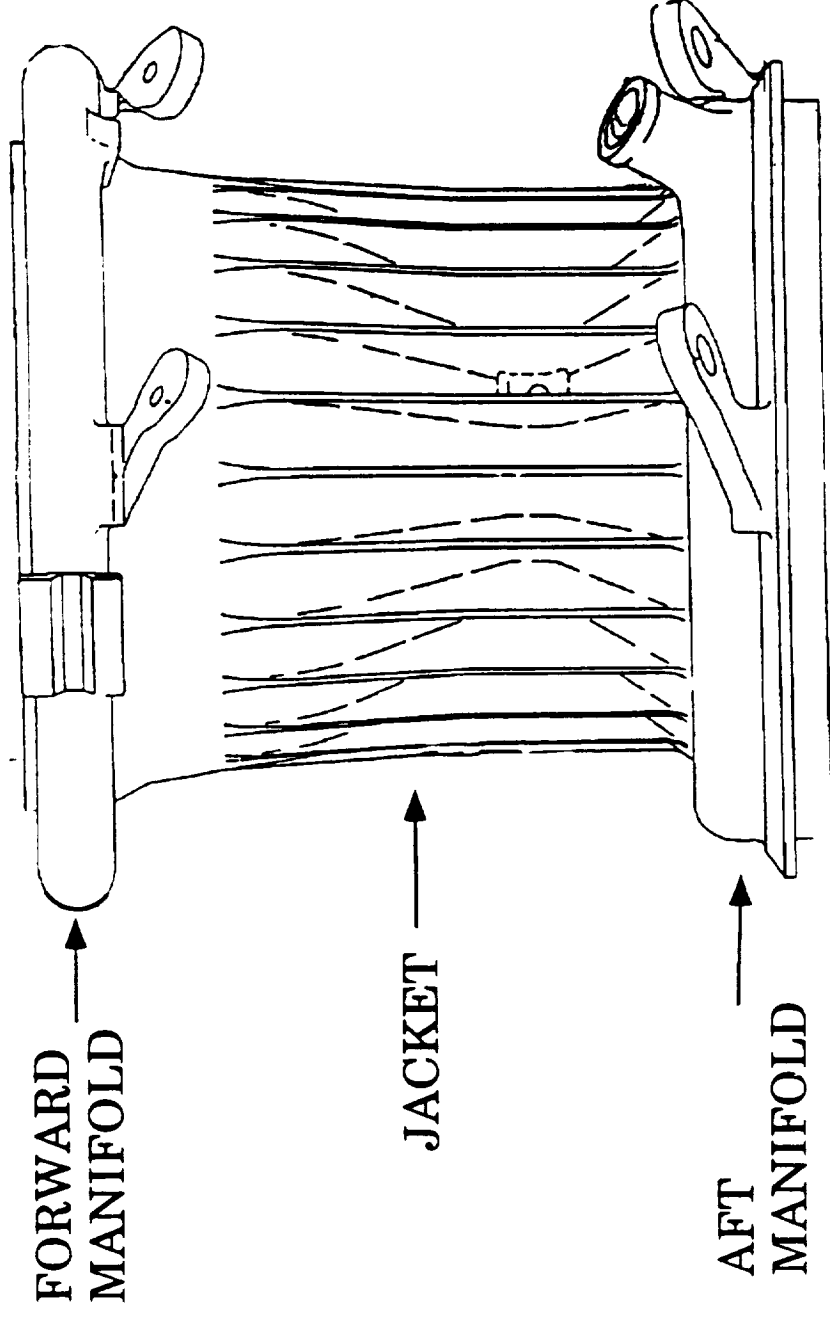
**ALL PHASES OF INVESTMENT CASTING  
PROCESS**



**Precision Castparts Corp.**

**NASA**

P/N 20013



Precision Castparts Corp.

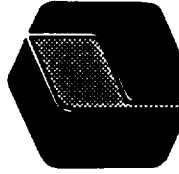
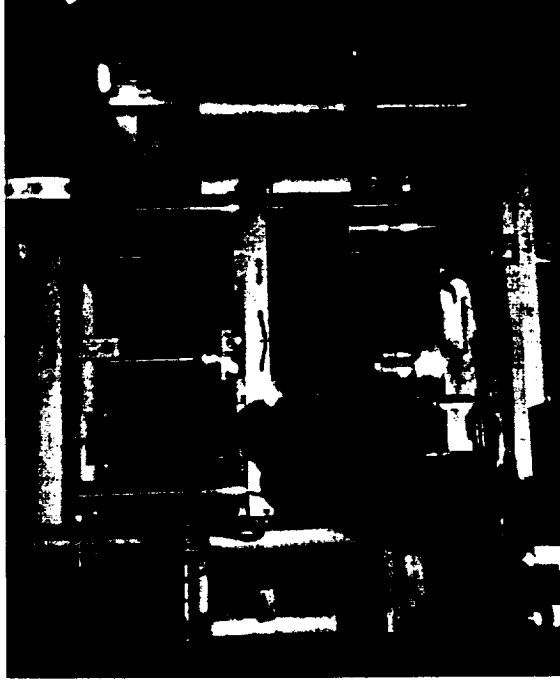
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# MANUFACTURING INVESTMENT CASTING

---

## MOLDING:

- Aluminum tooling
- Formula 27.5m wax
- Wax injection machine
- Fixtures
- Replicate of casting



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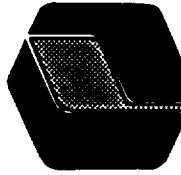
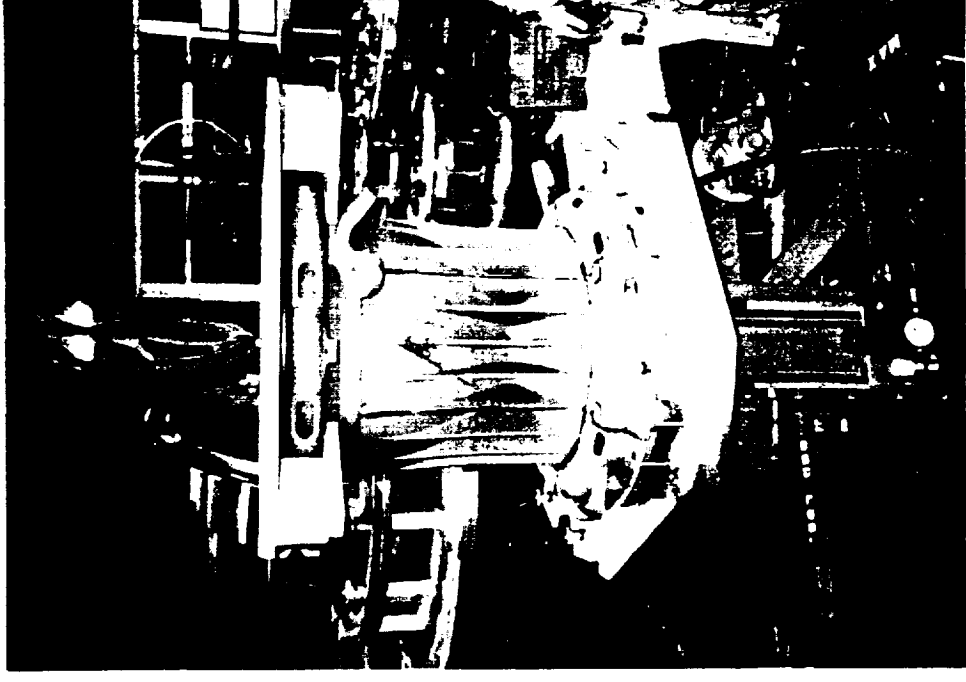
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# MANUFACTURING INVESTMENT CASTING

---

## PATTERN ASSEMBLY:

- Segment tooling
- Wax weld together
- Fixtures
- Final wax dimensional



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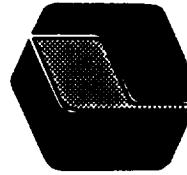
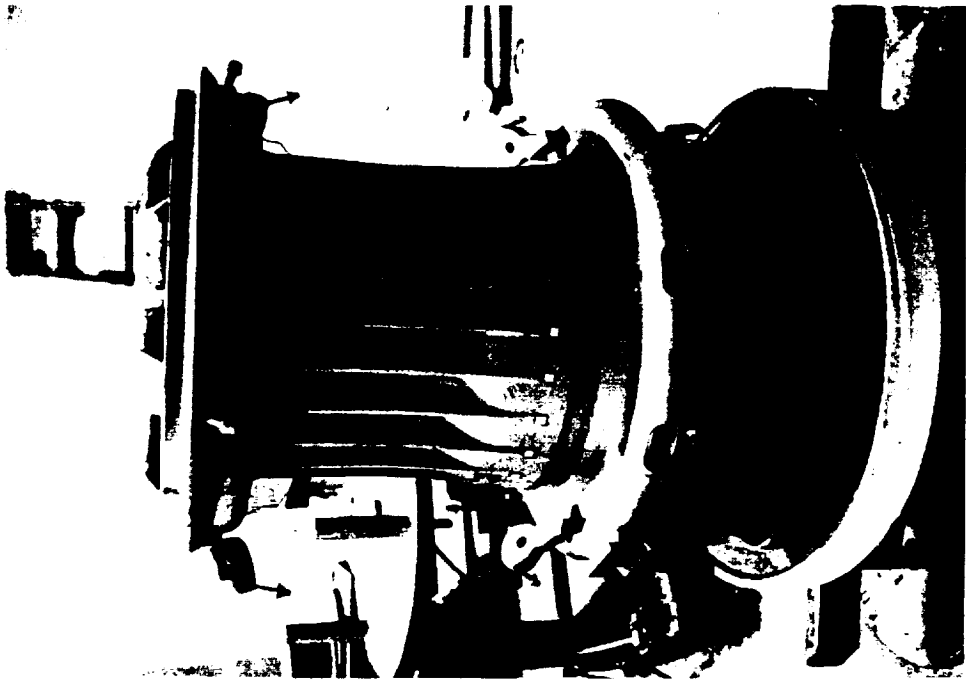


# MANUFACTURING INVESTMENT CASTING

---

## ASSEMBLY - GATING:

- Mock-up gates by hand
- Size, shape, location, frequency
- Structurally stable



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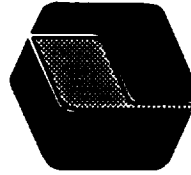
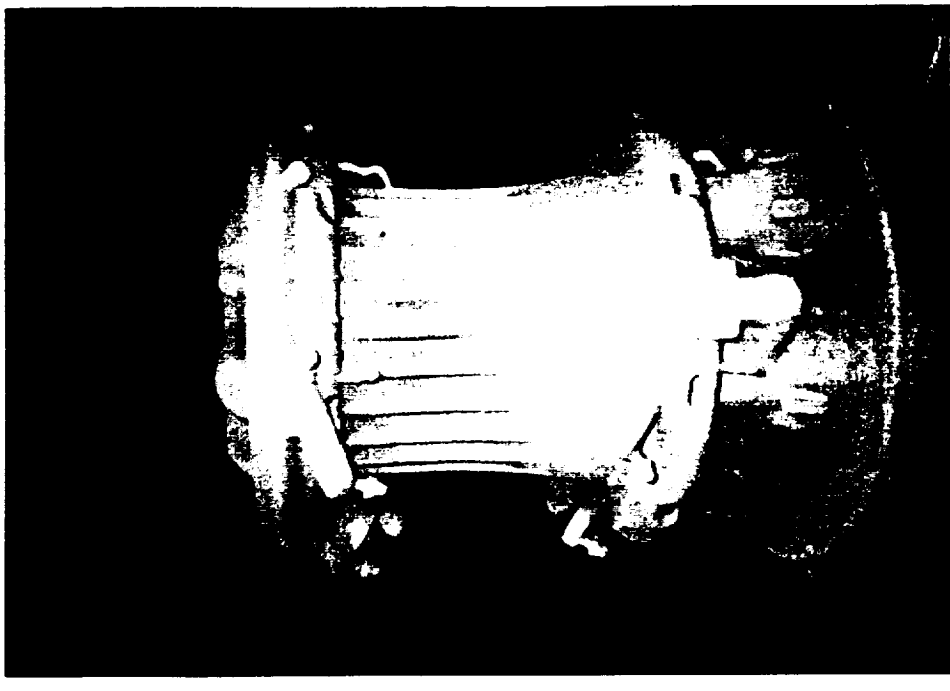
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# **MANUFACTURING INVESTMENT CASTING**

---

## **INVESTING:**

- **Weight of assembly**
- **Secure to frame**
- **Apply uniform shell**
- **Install TGC and thermo couples**
- **Special manifold work**
- **Thermal Gradient Control - insulation**



**Precision Castparts Corp.**

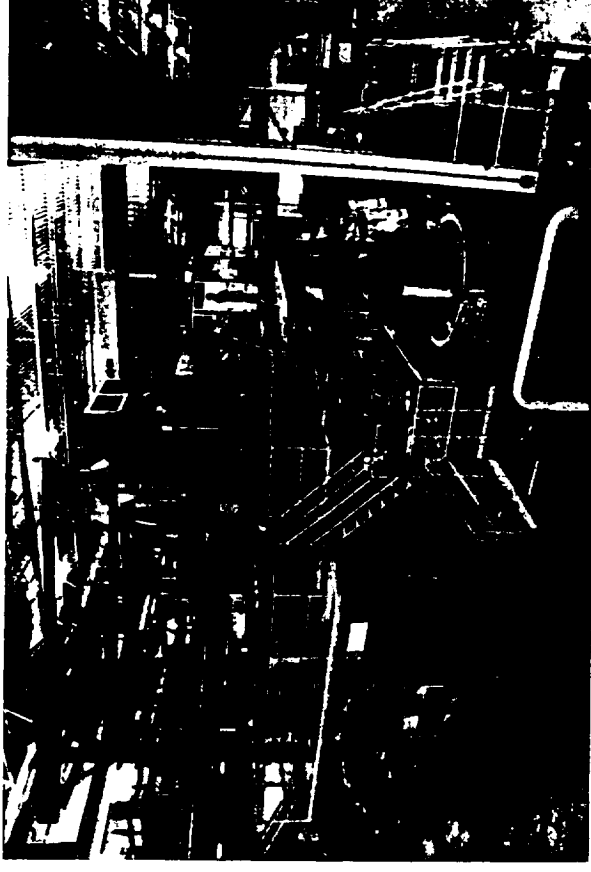
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# MANUFACTURING INVESTMENT CASTING

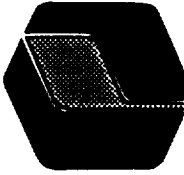
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## CASTING:

- Thermo couples
- Position of mold
- Special protection
- Thermal Gradient Control
- Dry run molds
- Pre-heat shells - long cycle
- Mold temperature
- Metal temperature



**Master Caster**



**Precision Castparts Corp.**

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# **MANUFACTURING INVESTMENT CASTING**

---

## **SHELL REMOVAL:**

- By hand
- Chemical
- High pressure waterblast

## **GATE REMOVAL:**

- Belt grind
- Hand grind

## **THERMAL CYCLES:**

- Thermal etch (FPI)
- HIP - 2050° F
- Homogenize - 2200° F
- Anneal - 2050° F
- Age - 1380° F



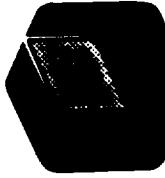
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# **ENGINEERING EVALUATION SEQUENCE**

---

- **Review Wax Assembly - Numbers, Size, Placement**
- **Review mold during Investing (shell build)**
- **Casting set-up and dry run**
- **Preliminary FPI**
- **X-ray - All - include Manifold**
- **Selective section of casting (prior to HIP)**
- **FPI cut sections**
- **Grain size review - after Chem Mill**
- **FPI - Final prior to Lab**
- **Metallography/grain etch specimens**



**Precision Castparts Corp.**

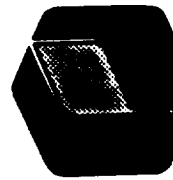
**NASA**

## **PROGRAM STATUS**

### **MACHINE TRIALS - PLATELET BOND - HOT FIRE**

---

<b>Lot No.</b>	<b>003</b>	<b>-</b>	<b>Cut up</b>	<b>Engineering Evaluation</b>
	<b>004</b>	<b>-</b>	<b>Ship</b>	<b>9-27-92</b>
	<b>005</b>	<b>-</b>	<b>Ship</b>	<b>11-18-92</b>
	<b>006</b>	<b>-</b>	<b>Cut up</b>	<b>Engineering Evaluation</b>
	<b>007</b>	<b>-</b>	<b>Ship</b>	<b>12-17-92</b>
	<b>008</b>	<b>-</b>	<b>Cancel</b>	<b>Wax Assembly (Gating installed)</b>



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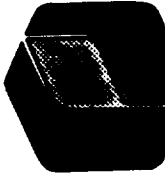
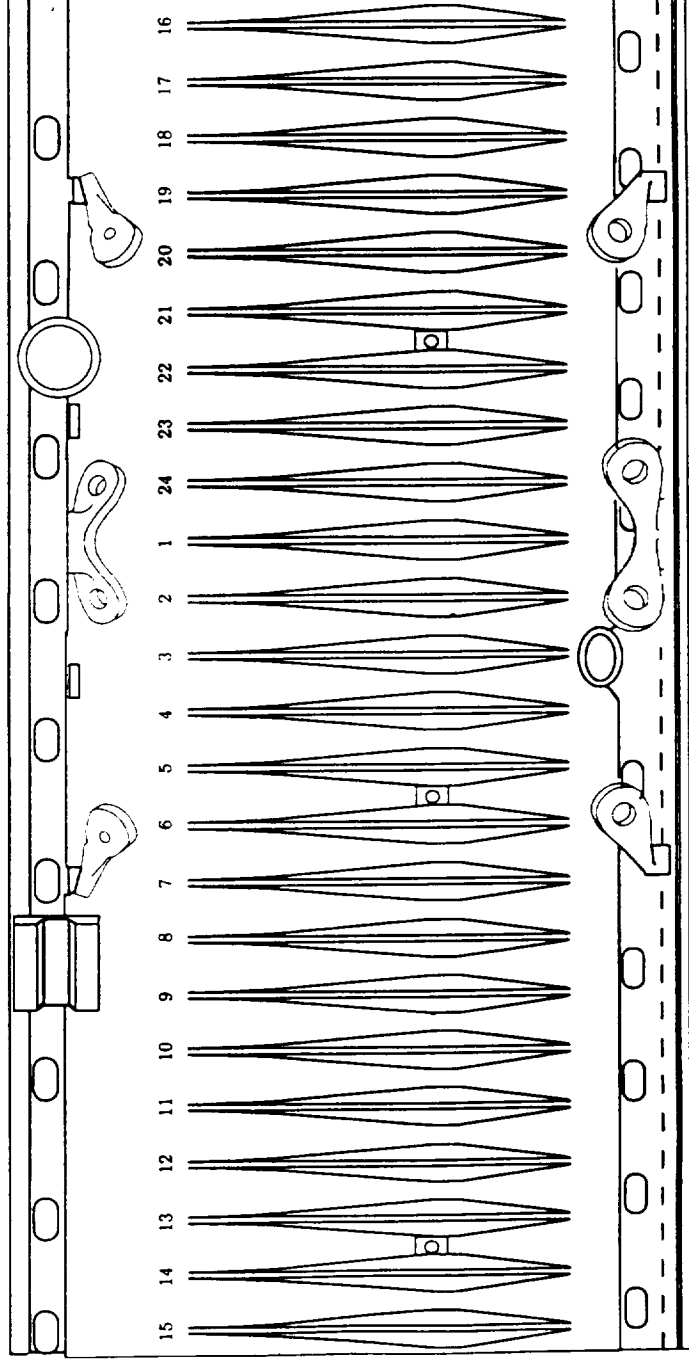
**NASA**

# ENGINEERING EVALUATION

## LOT 3

---

- Mini DOE - Gating - - - Spoke gate - Shape, size, location  
Jacket gate - Same
- First mold with TGC - one section
- Provided information for lots 004 - 008



Precision Castparts Corp.

NASA

## SUMMARY

---

Lot No. 004	<ul style="list-style-type: none"><li>• First full process casting</li><li>• Spoke gate</li><li>• Jacket TGC (Rev)</li><li>• No 2200°F Homogenize</li><li>• Quality</li></ul>
Lot No. 005	<ul style="list-style-type: none"><li>• Full Process</li><li>• Spoke gate</li><li>• Jacket TGC (Std)</li><li>• Returned for weld build inside, HIP homogenize 2200°F</li><li>• Quality</li></ul>
Lot No. 007	<ul style="list-style-type: none"><li>• Full Process</li><li>• Spoke Gate</li><li>• Jacket, Fwd, Aft Manifold TGC</li><li>• Returned for homogenize 2200° F</li><li>• Quality</li></ul>

\*TGC - Thermal Gradient Control



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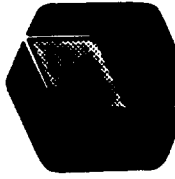


# ENGINEERING EVALUATION

## Lot 6

---

- Gating same as lots 004, 005, 007
- Foundry - no change
- TGC - Jacket, Aft Manifold
- FPI - Inclusions of foreign material
- X-ray - Before HIP, large areas of shrink in Jacket
  - After HIP, areas reduced
- FPI after Chem Mill
- Grain size
- Metallography



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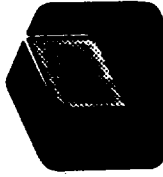
# **DIMENSIONAL ENGINEERING**

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**JOHN DAVIS**

**LOTS 3 - 7**

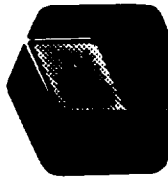
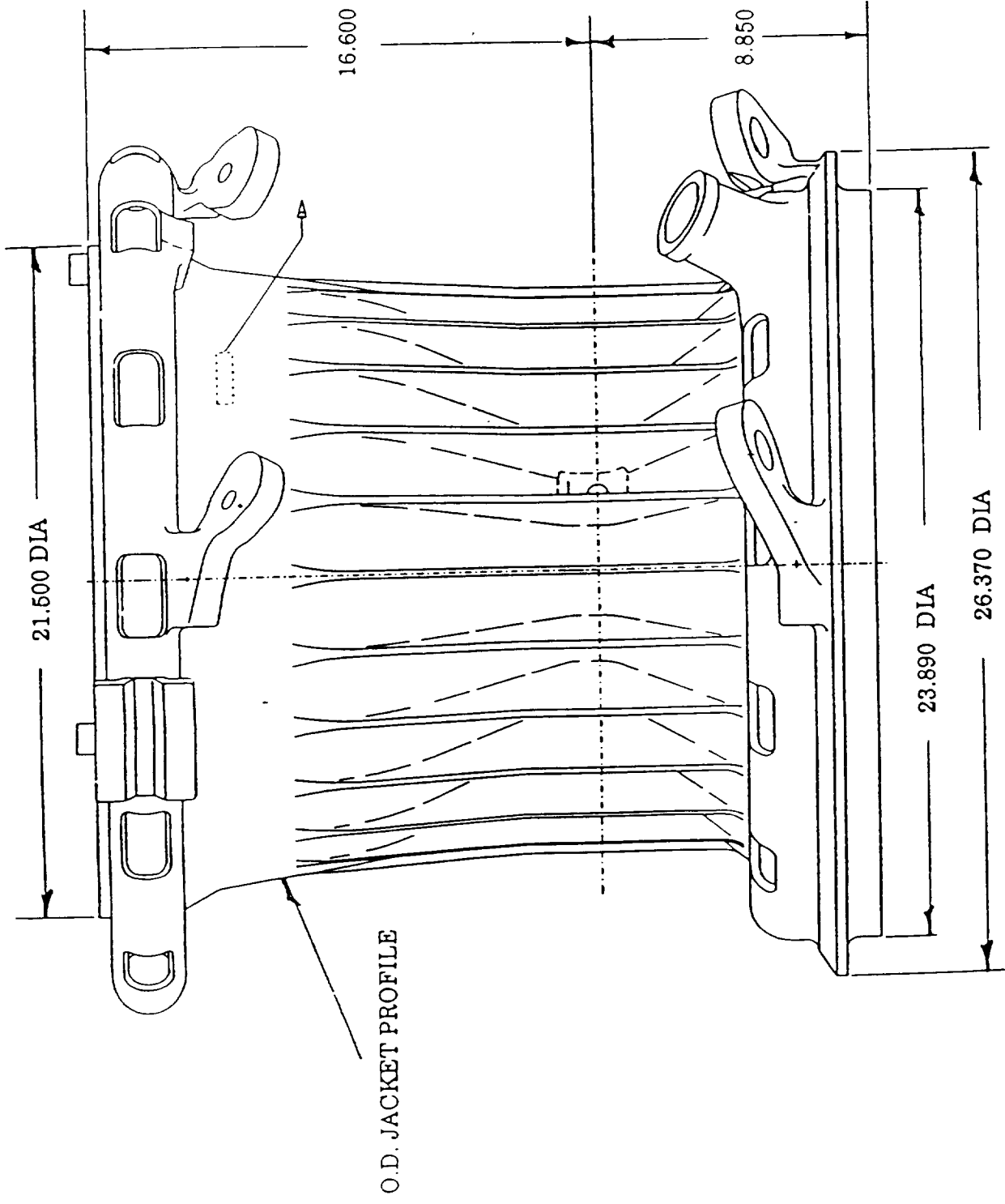
- **DIMENSIONAL DEVELOPMENT**
- **GENERATION OF DIMENSIONAL DATA**



**Precision Castparts Corp.**

**NASA**

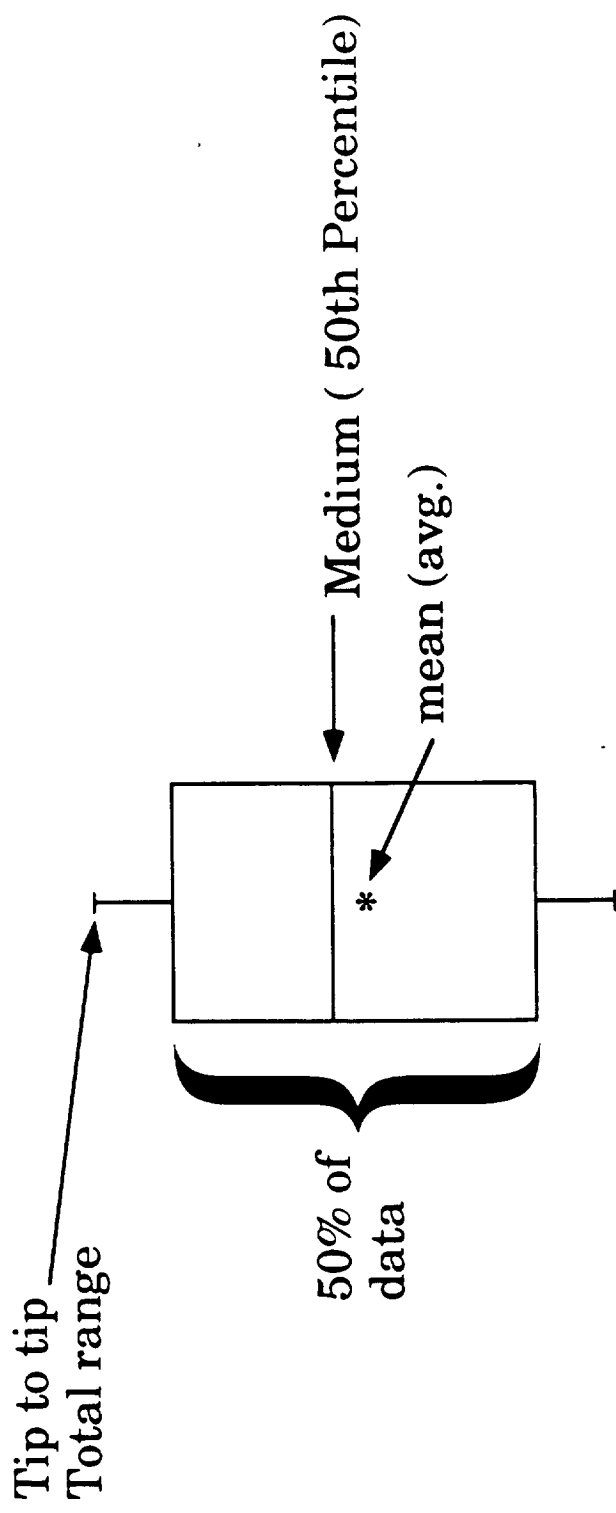
# NASA AMCC BLUEPRINT DIMENSIONS



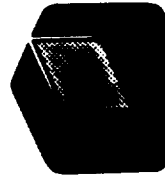
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# STATISTICAL PROCESS CONTROL BOX AND WHISKER SYMBOL DEFINITION



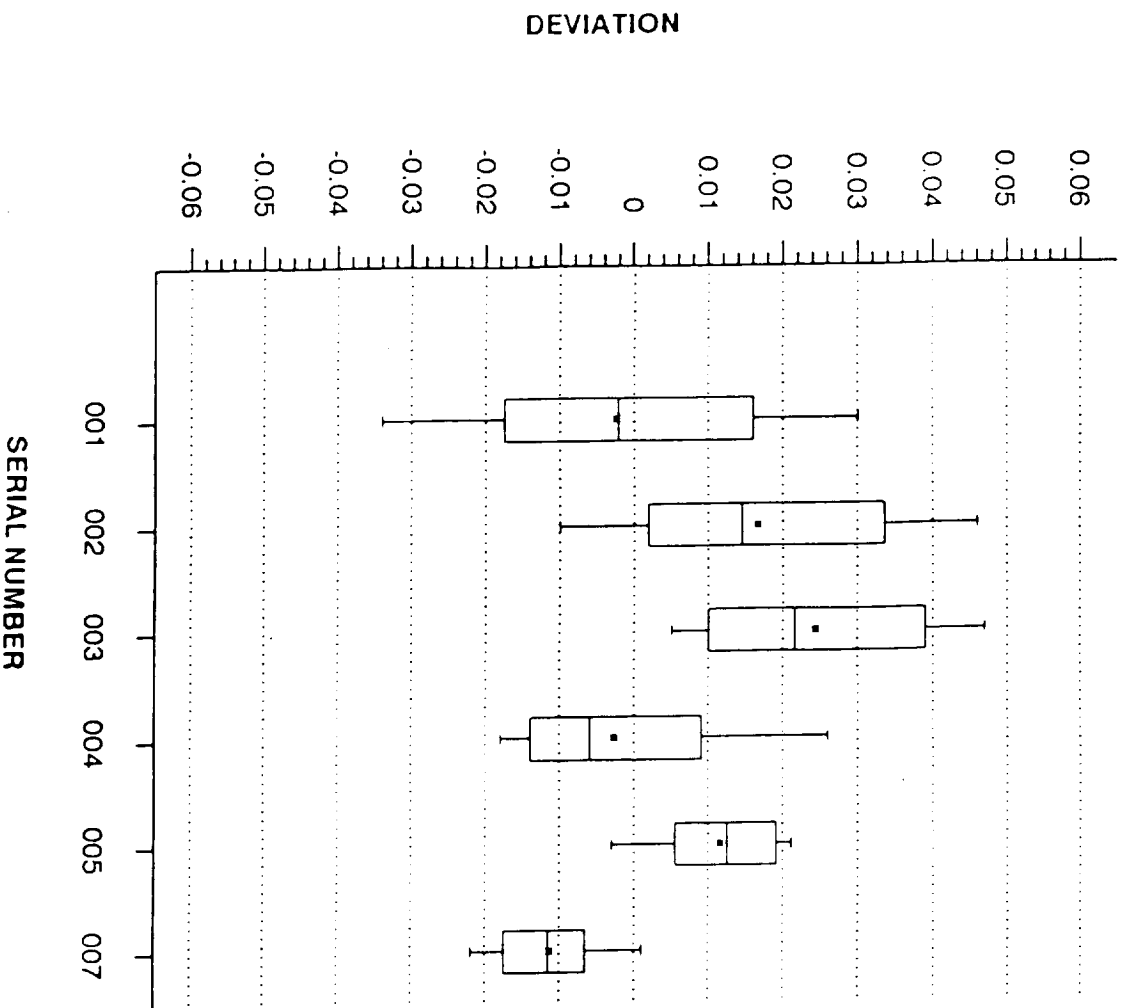
\* All data analyzed by Statgraphics



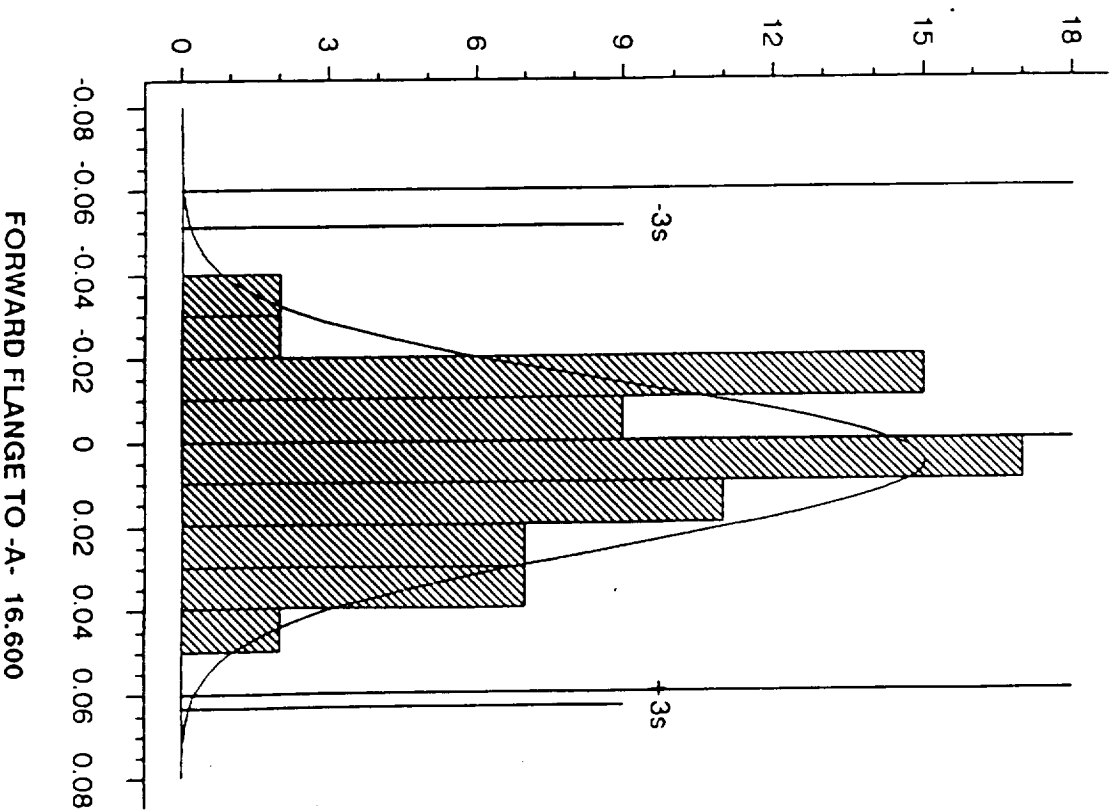
Precision Castparts Corp.



# Multiple Box-and-Whisker Plot FORWARD FLANGE TO -A- 16.600



# Process Capability: SN 1,2,3,4,5,7

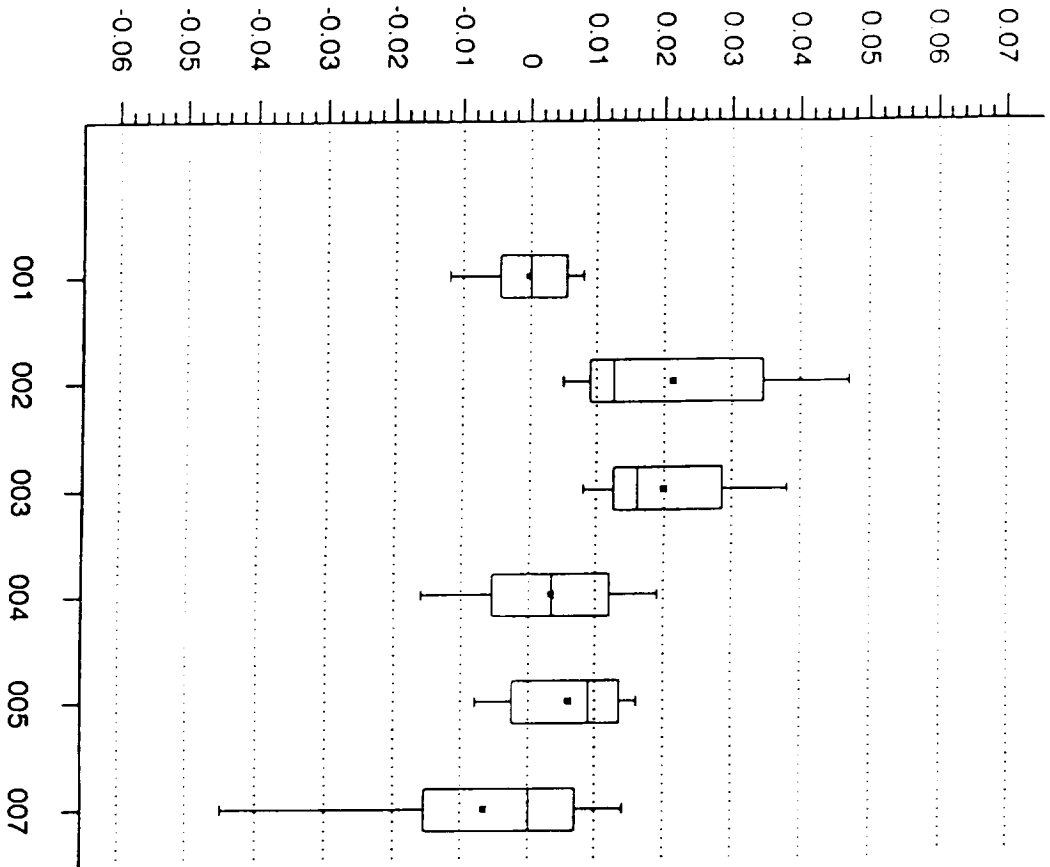


Precision Castparts Corp.

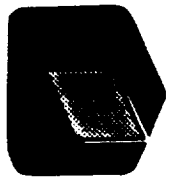
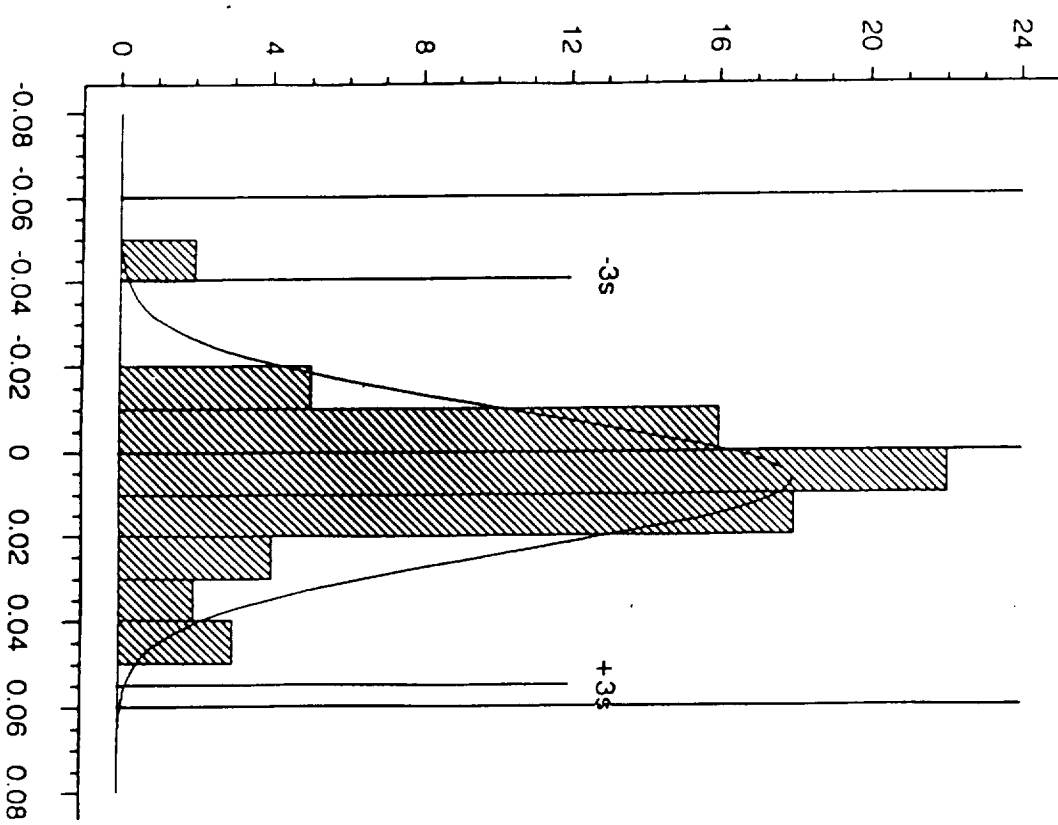




# Multiple Box-and-Whisker Plot AFT FLANGE TO -A- 8.850



# Process Capability: SN 1,2,3,4,5,7 LSL Nominal USL



Precision Castparts Corp.



# PROCESS CAPABILITY ANALYSIS AFT FLANGE TO -A- 8.850

AFT FLANGE TO -A- 8.850 (SN 1-5, 7)

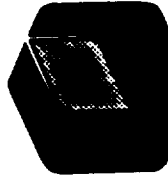
Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 72	+3.0 sigma 0.0552
Nominal 0	Mean 0.0072	Mean 0.0072
Lower -0.06	Sigma 0.016	-3.0 sigma -0.0408

Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 0.000 %	High 0.048 %	CP 1.25
Low 0.000 %	Low 0.001 %	CR 0.8
-----	-----	CPK 1.1
Total 0.000 %	Total 0.050 %	(upper) 1.1
		(lower) 1.4
		K 0.12
		CPM 1.14015

AFT FLANGE TO -A- 8.850 (SN 9,10,12,14)

Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 48	+3.0 sigma 0.0783
Nominal 0	Mean 0.0138	Mean 0.0138
Lower -0.06	Sigma 0.0215	-3.0 sigma -0.0507

Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 4.167 %	High 1.582 %	CP 0.930233
Low 0.000 %	Low 0.030 %	CR 1.075
-----	-----	CPK 0.716279
Total 4.167 %	Total 1.612 %	(upper) 0.716279
		(lower) 1.14419
		K 0.23
		CPM 0.782418

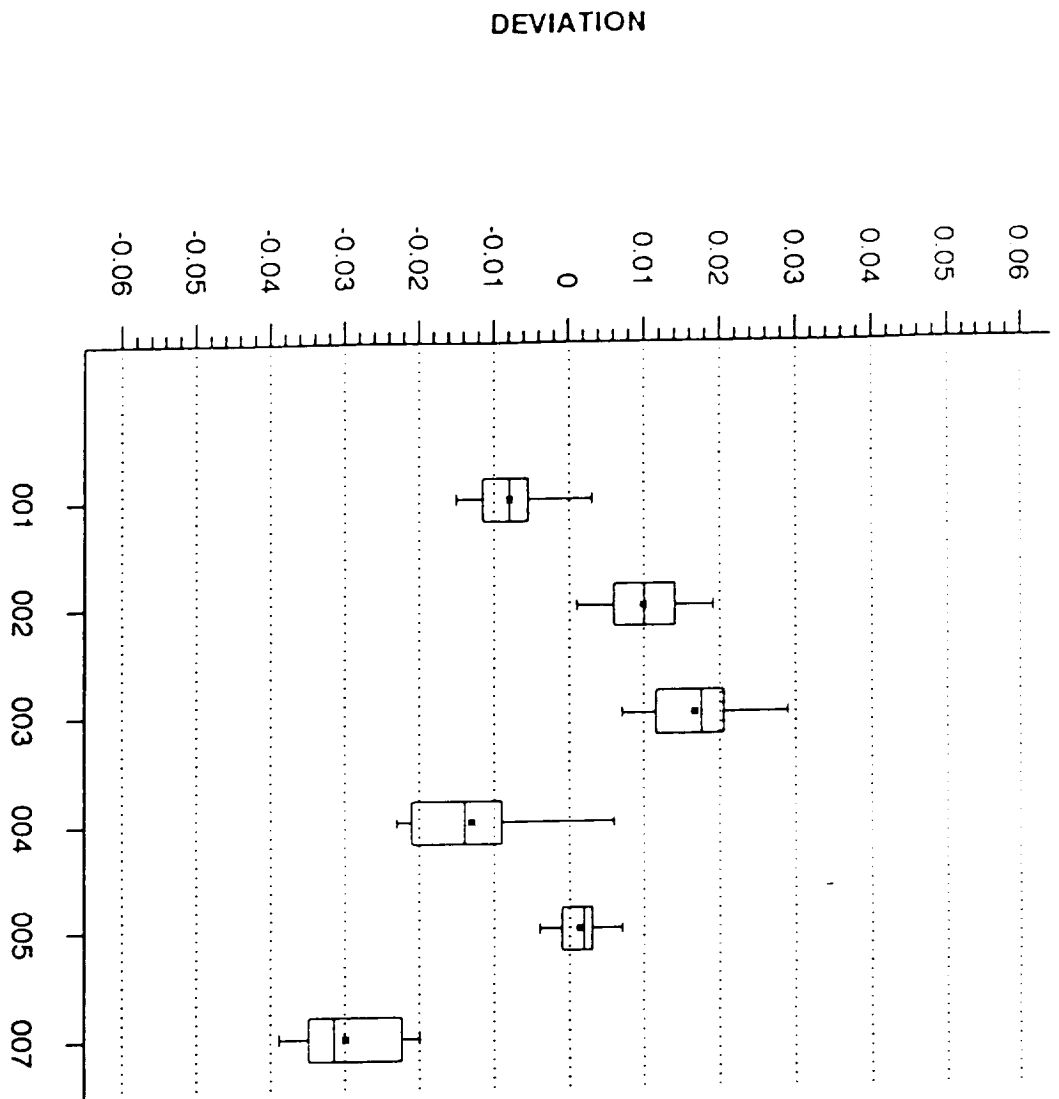


Precision Castparts Corp.

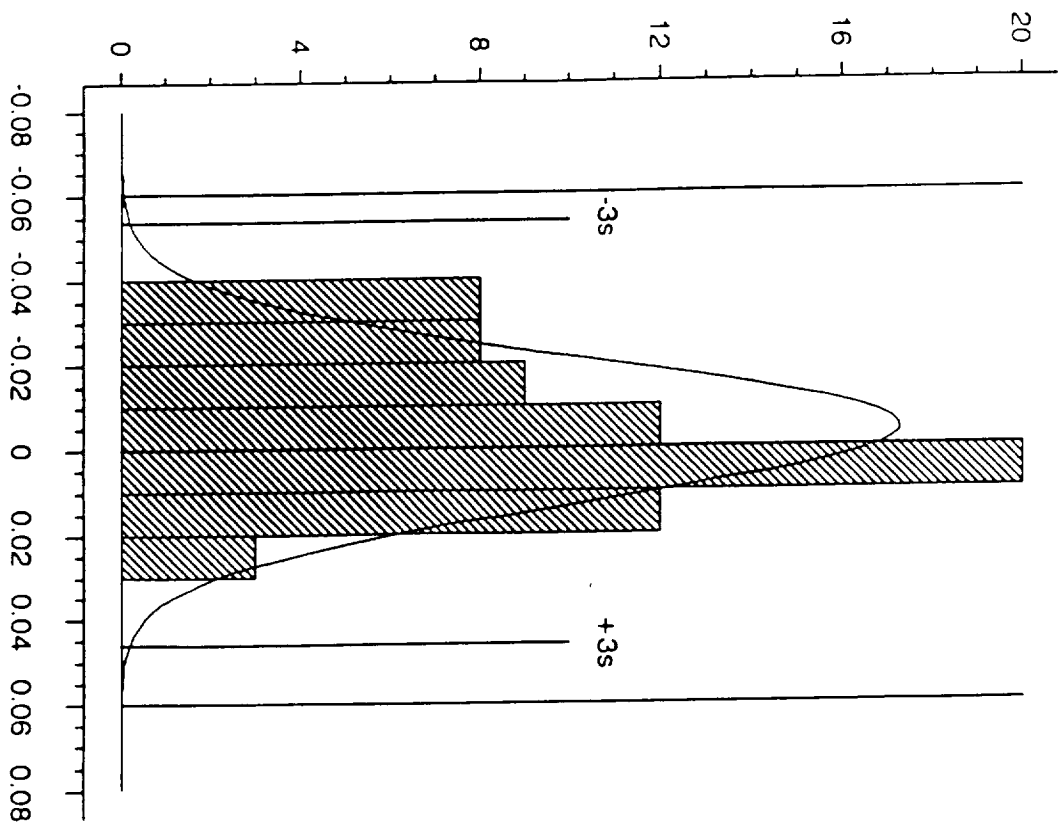
NASA



# Multiple Box-and-Whisker Plot FORWARD FLANGE DIA 21.500



# Process Capability: SN 1,2,3,4,5,7 LSL Nominal USL



SERIAL NUMBER

FORWARD FLANGE DIA 21.500

Precision Castparts Corp.

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# PROCESS CAPABILITY ANALYSIS FORWARD FLANGE DIA 21.500

FWD FLANGE DIA 21.500 (SN 1-5, 7)

Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 72	+3.0 sigma 0.0459
Nominal 0	Mean -0.0039	Mean -0.0039
Lower -0.06	Sigma 0.0166	-3.0 sigma -0.0537

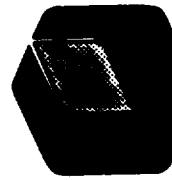
Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 0.000 %	High 0.006 %	CP 1.20482
Low 0.000 %	Low 0.036 %	CR 0.83
-----	-----	CPK 1.12651
Total 0.000 %	Total 0.042 %	(upper) 1.28313
		(lower) 1.12651
		K -0.065
		CPM 1.17106

FWD FLANGE DIA 21.500 (SN 9,10,12,14)

Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 48	+3.0 sigma 0.0161
Nominal 0	Mean -0.0028	Mean -0.0028
Lower -0.06	Sigma 0.0063	-3.0 sigma -0.0217

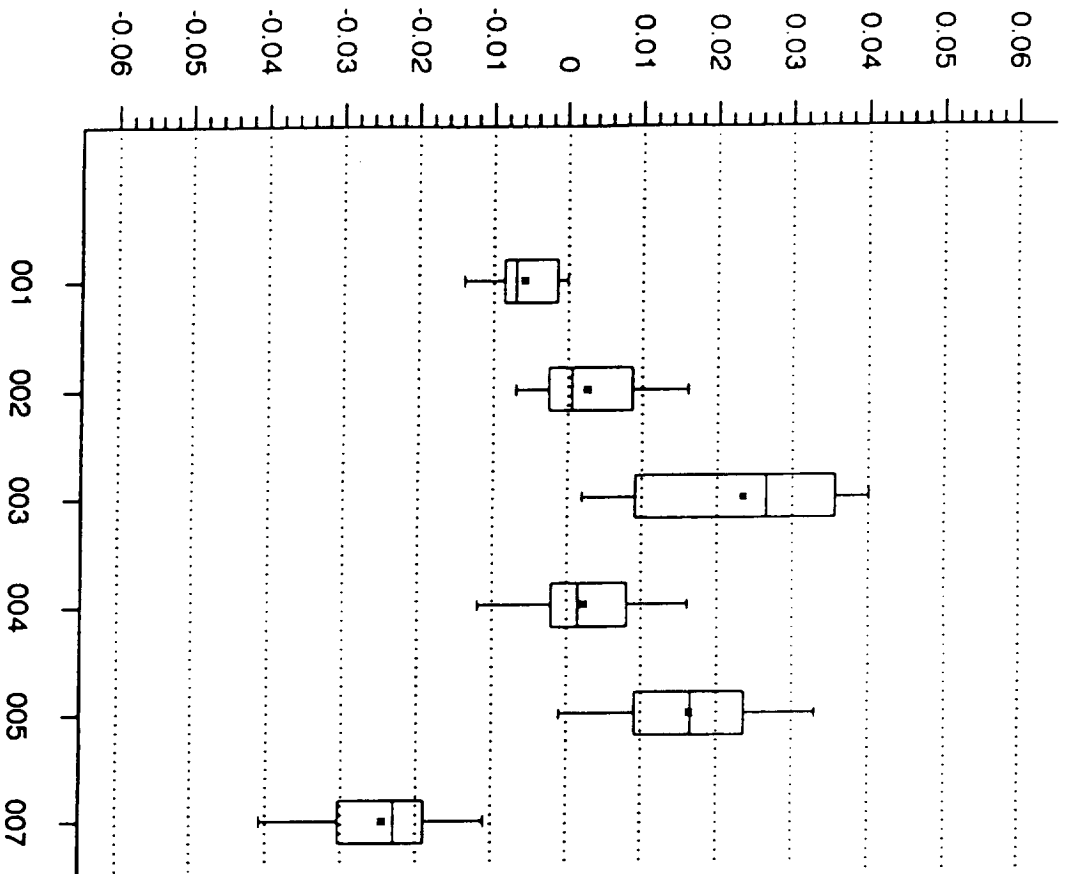
Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 0.000 %	High 0.000 %	CP 3.1746
Low 0.000 %	Low 0.000 %	CR 0.315
-----	-----	CPK 3.02646
Total 0.000 %	Total 0.000 %	(upper) 3.32275
		(lower) 3.02646
		K -0.046667
		CPM 2.89834



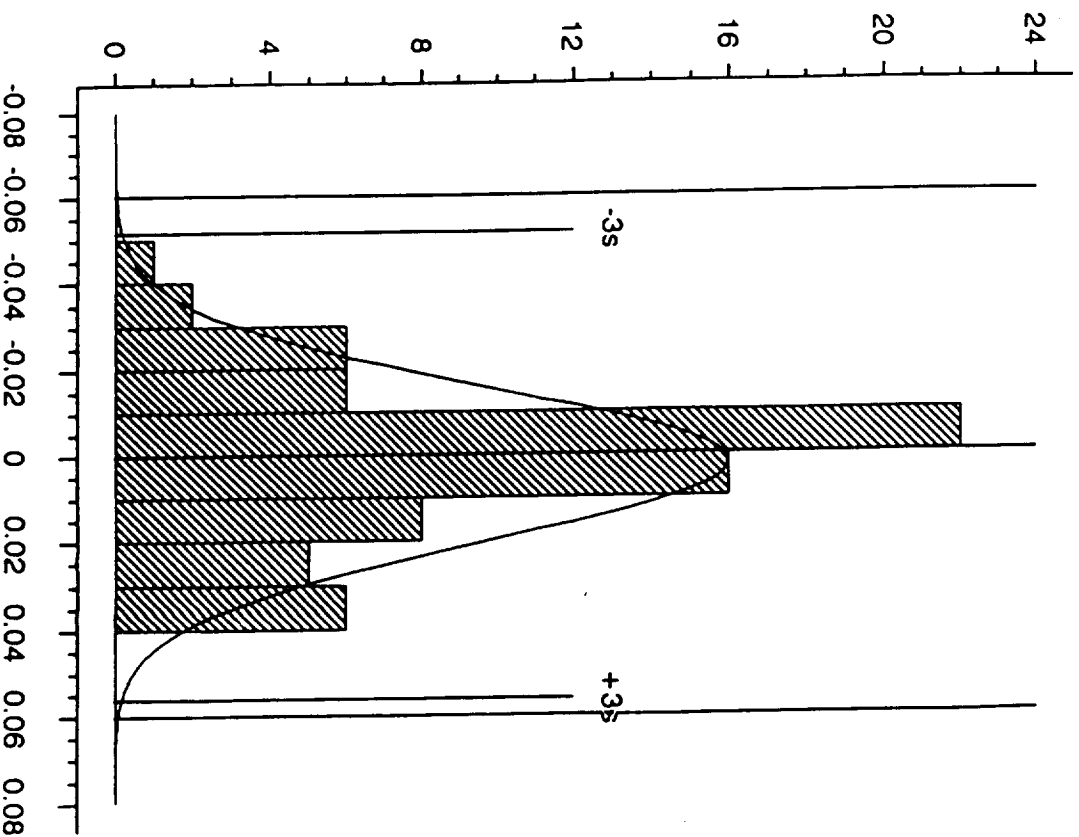
Precision Castparts Corp.

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# Multiple Box-and-Whisker Plot AFT FLANGE DIA 26.370



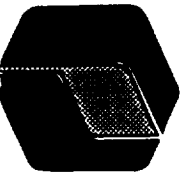
# Process Capability: SN 1,2,3,4,5,7 LSL Nominal USL



SERIAL NUMBER

AFT FLANGE DIA 26.370

Precision Castparts Corp.



NASA

# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE DIA 26.370

AFT FLANGE DIA 26.370 (SN 1-5, 7)

Specification:                      Normal distribution:                      6.0 sigma limits:

Upper 0.06	Count 72	+3.0 sigma 0.0563
Nominal 0	Mean 0.0023	Mean 0.0023
Lower -0.06	Sigma 0.018	-3.0 sigma -0.0517

Observed beyond spec.:                      Estimated beyond spec.:                      Capability indices:

High 0.000 %	High 0.067 %	CP 1.11111
Low 0.000 %	Low 0.027 %	CR 0.9
-----	-----	CPK 1.06852
Total 0.000 %	Total 0.094 %	(upper) 1.06852
		(lower) 1.1537
		K 0.0383333
		CPM 1.10434

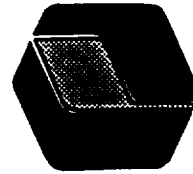
AFT FLANGE DIA 26.370 (SN 9,10,12,14)

Specification:                      Normal distribution:                      6.0 sigma limits:

Upper 0.06	Count 48	+3.0 sigma 0.0361
Nominal 0	Mean 0.0043	Mean 0.0043
Lower -0.06	Sigma 0.0106	-3.0 sigma -0.0275

Observed beyond spec.:                      Estimated beyond spec.:                      Capability indices:

High 0.000 %	High 0.000 %	CP 1.88679
Low 0.000 %	Low 0.000 %	CR 0.53
-----	-----	CPK 1.75157
Total 0.000 %	Total 0.000 %	(upper) 1.75157
		(lower) 2.02201
		K 0.0716667
		CPM 1.7398

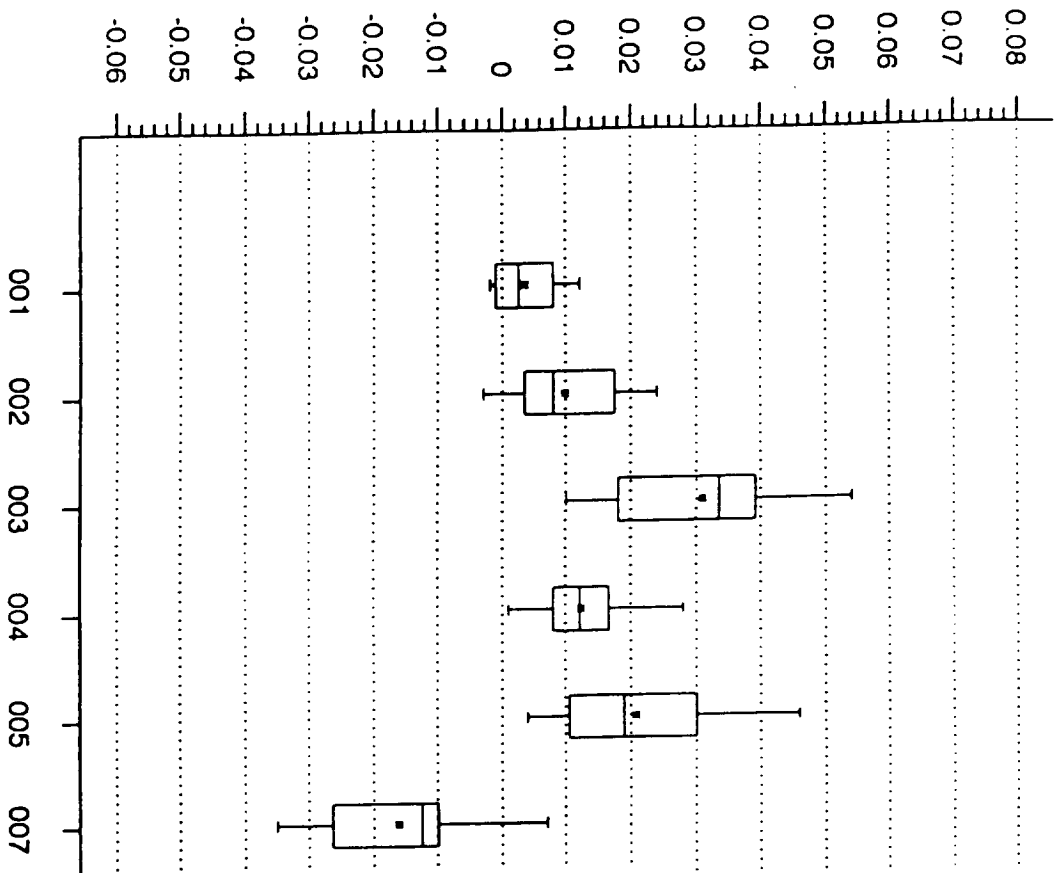


Precision Castparts Corp.

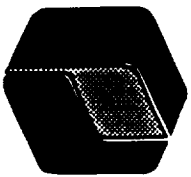
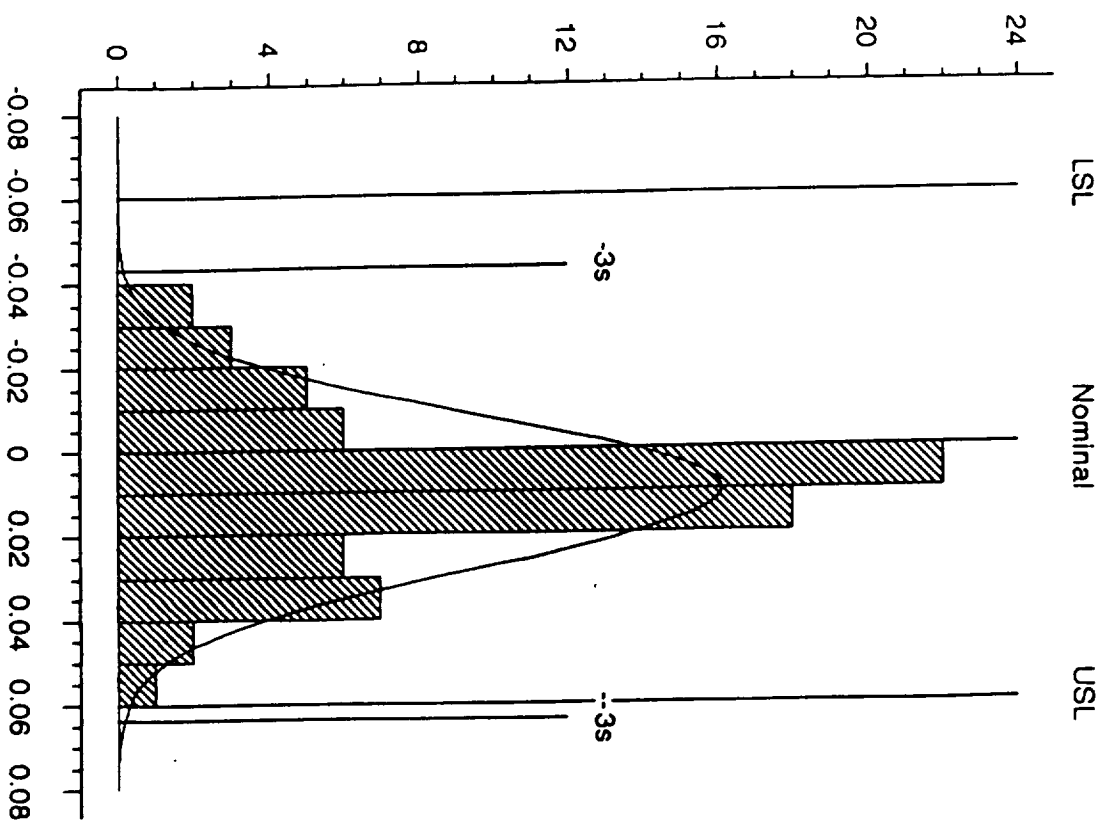
NASA

# Multiple Box-and-Whisker Plot

## AFT FLANGE DIA 23.890



# Process Capability: SN 1,2,3,4,5,7



Precision Castparts Corp.

SERIAL NUMBER

AFT FLANGE DIA 23.890

NASA

# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE DIA 23.890

AFT FLANGE DIA 23.890 (SN 1-5, 7)

Specification: Upper 0.06  
Nominal 0  
Lower -0.06

Normal distribution: Count 72  
Mean 0.0101  
Sigma 0.0178

6.0 sigma limits:  
+3.0 sigma 0.0635  
Mean 0.0101  
-3.0 sigma -0.0433

Observed beyond spec.: Estimated beyond spec.: Capability indices:

High 0.000 % High 0.253 % CP 1.1236  
Low 0.000 % Low 0.004 % CR 0.89  
-----  
Total 0.000 % Total 0.257 % CPK 0.934457  
(upper) 0.934457  
(lower) 1.31273  
K 0.168333  
CPM 0.975312

AFT FLANGE DIA 23.890 (SN 9,10,12,14)

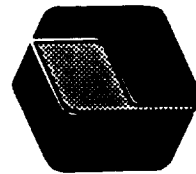
Specification: Upper 0.06  
Nominal 0  
Lower -0.06

Normal distribution: Count 48  
Mean 0.0135  
Sigma 0.0221

6.0 sigma limits:  
+3.0 sigma 0.0798  
Mean 0.0135  
-3.0 sigma -0.0528

Observed beyond spec.: Estimated beyond spec.: Capability indices:

High 4.167 % High 1.769 % CP 0.904977  
Low 0.000 % Low 0.044 % CR 1.105  
-----  
Total 4.167 % Total 1.813 % CPK 0.701357  
(upper) 0.701357  
(lower) 1.1086  
K 0.225  
CPM 0.771505

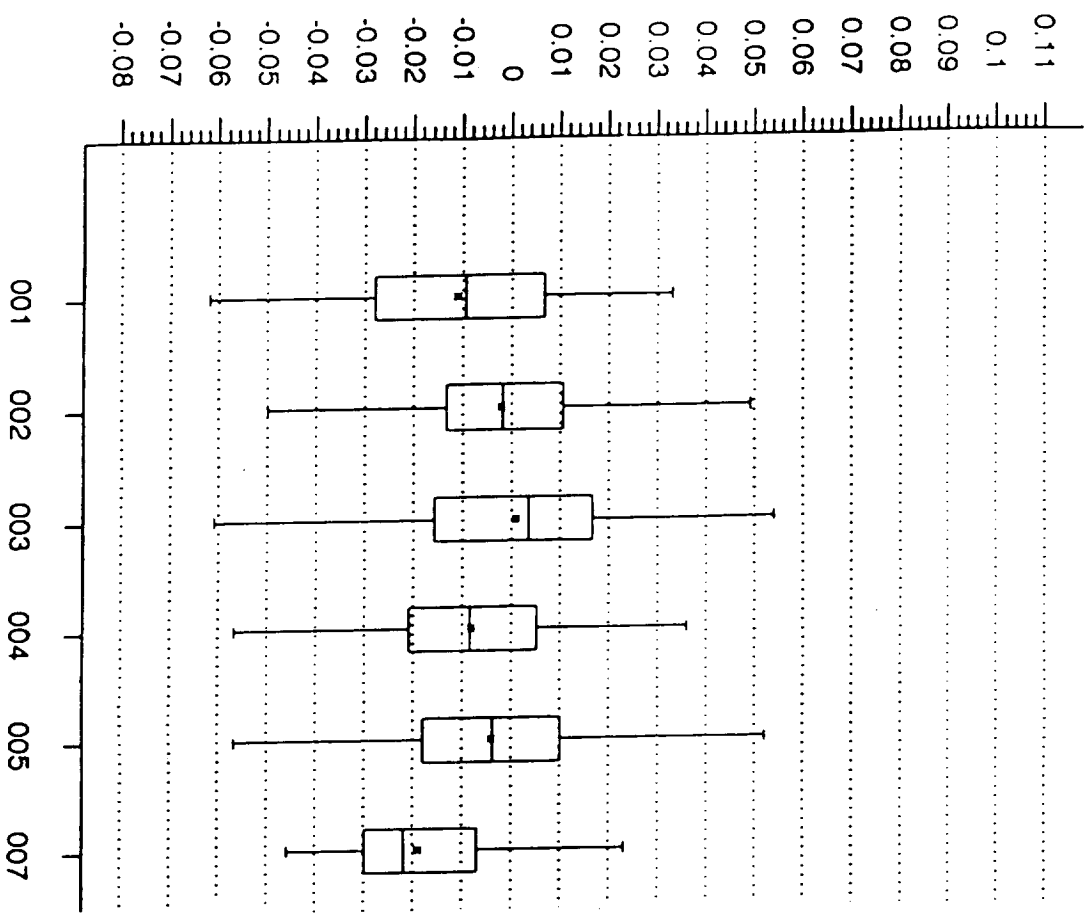


Precision Castparts Corp.

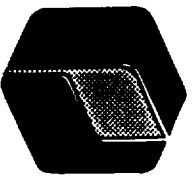
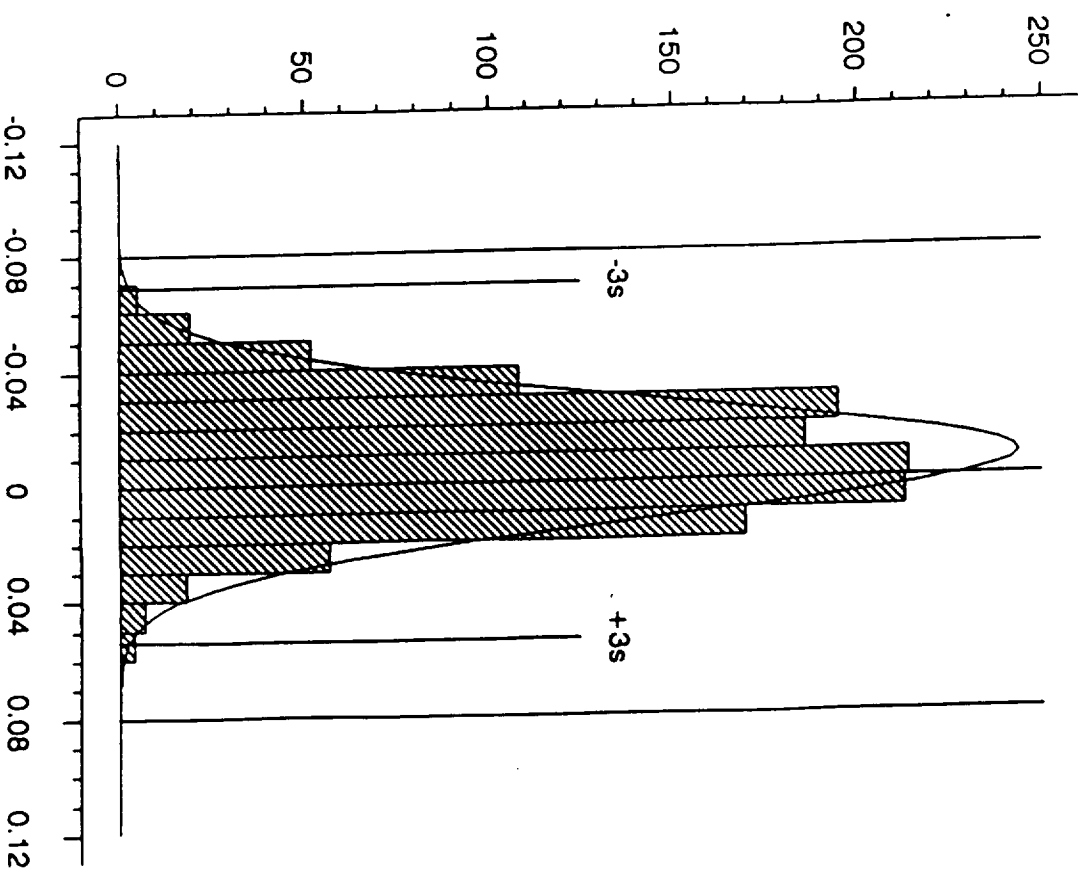
NASA

# Multiple Box-and-Whisker Plot

## OUTSIDE JACKET PROFILE 0.160 TO ABC



# Process Capability: SN 1,2,3,4,5,7



Precision Castparts Corp.

SERIAL NUMBER

OUTSIDE JACKET PROFILE 0.160 TO ABC

WASA

# PROCESS CAPABILITY ANALYSIS

## OD JACKET PROFILE 0.160

OD JACKET PROFILE 0.160 (SN 1-5, 7)

Specification:                      Normal distribution:                      6.0 sigma limits:

Upper 0.08	Count 1248	+3.0 sigma 0.0538
Nominal 0	Mean -0.0074	Mean -0.0074
Lower -0.08	Sigma 0.0204	-3.0 sigma -0.0686

Observed beyond spec.:                      Estimated beyond spec.:                      Capability indices:

High 0.000 %	High 0.001 %	CP 1.30719
Low 0.000 %	Low 0.019 %	CR 0.765
-----	-----	CPK 1.18627
Total 0.000 %	Total 0.020 %	(upper) 1.4281
		(lower) 1.18627
		K -0.0925
		CPM 1.22711

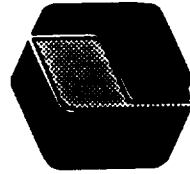
OD JACKET PROFILE 0.160 (SN 9,10,12,14)

Specification:                      Normal distribution:                      6.0 sigma limits:

Upper 0.08	Count 832	+3.0 sigma 0.0774
Nominal 0	Mean -0.0021	Mean -0.0021
Lower -0.08	Sigma 0.0265	-3.0 sigma -0.0816

Observed beyond spec.:                      Estimated beyond spec.:                      Capability indices:

High 0.481 %	High 0.097 %	CP 1.00629
Low 0.000 %	Low 0.164 %	CR 0.99375
-----	-----	CPK 0.979874
Total 0.481 %	Total 0.262 %	(upper) 1.0327
		(lower) 0.979874
		K -0.02625
		CPM 1.00307



Precision Castparts Corp.

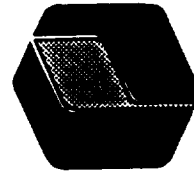
NASA



# DIMENSIONAL SUMMARY

B/P Location	Inspection Reading	Lot #1		Lot #2		Lot #3	
		Range	Average	Range	Average	Range	Average
16.6 Dim.	12	+ .030/- .034	-.002	+ .046/- .010	+ .017	+ .047/+ .005	+ .024
8.85 Dim.	12	+ .008/- .012	.000	+ .047/+ .005	+ .021	+ .038/+ .008	+ .020
21.50 Dia.	12	+ .003/- .015	-.008	+ .019/+ .001	+ .010	+ .029/+ .007	+ .017
26.37 Dia.	12	+ .000/- .014	-.006	+ .016/- .007	+ .003	+ .040/+ .002	+ .023
23.89 Dia.	12	+ .012/- .002	+ .004	+ .024/- .003	+ .010	+ .054/+ .010	+ .031
.160 ABC	208	+ .033/- .062	-.011	+ .049/- .050	-.002	+ .054/- .061	+ .001

Dimensions reported as deviations from nominal



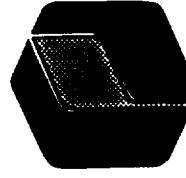
Precision Castparts Corp.

NASA

# DIMENSIONAL SUMMARY

B/P Location	Inspection Reading	Lot #4		Lot #5		Lot #7	
		Range	Average	Range	Average	Range	Average
16.6 Dim.	12	+ .026/- .018	-.003	+ .020/- .003	+ .012	+ .001/- .022	-.011
8.85 Dim	12	+ .019/- .016	+ .003	+ .016/- .008	+ .006	+ .014/- .045	-.007
21.50 Dia.	12	+ .006/- .023	-.013	+ .007/- .004	+ .001	-.020/- .039	-.030
26.37 Dia.	12	+ .016/- .012	+ .002	+ .033/- .001	+ .016	-.011/- .041	-.025
23.89 Dia.	12	+ .028/+ .001	+ .012	+ .046/+ .004	+ .021	+ .007/- .035	-.016
.160 ABC	208	+ .036/- .057	-.008	+ .052/- .057	-.004	+ .023/- .046	-.019

Dimensions reported as deviations from nominal



Precision Castparts Corp.

NASA

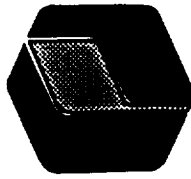
# **LOTS 3-7**

## **NON-DESTRUCTIVE TESTING**

---

**BRUCE HAPHEY**

- **NDT PROCESS CAPABILITIES**
- **POTENTIAL PROBLEMS DEFINED**



**Precision Castparts Corp.**

**NASA**

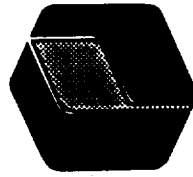
# **NDT ENGINEERING**

**Lots 3 - 7**

---

## **NDT Process Capabilities:**

- **X-Ray**
- **Penetrant**
- **Visual**
- **Dimensional**



**Precision Castparts Corp.**

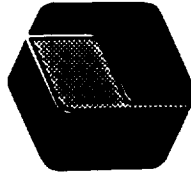
**NASA**

# **NDT ENGINEERING**

**Lots 3 - 7**

---

- **Potential problems defined**
- **Manifold**

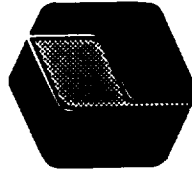
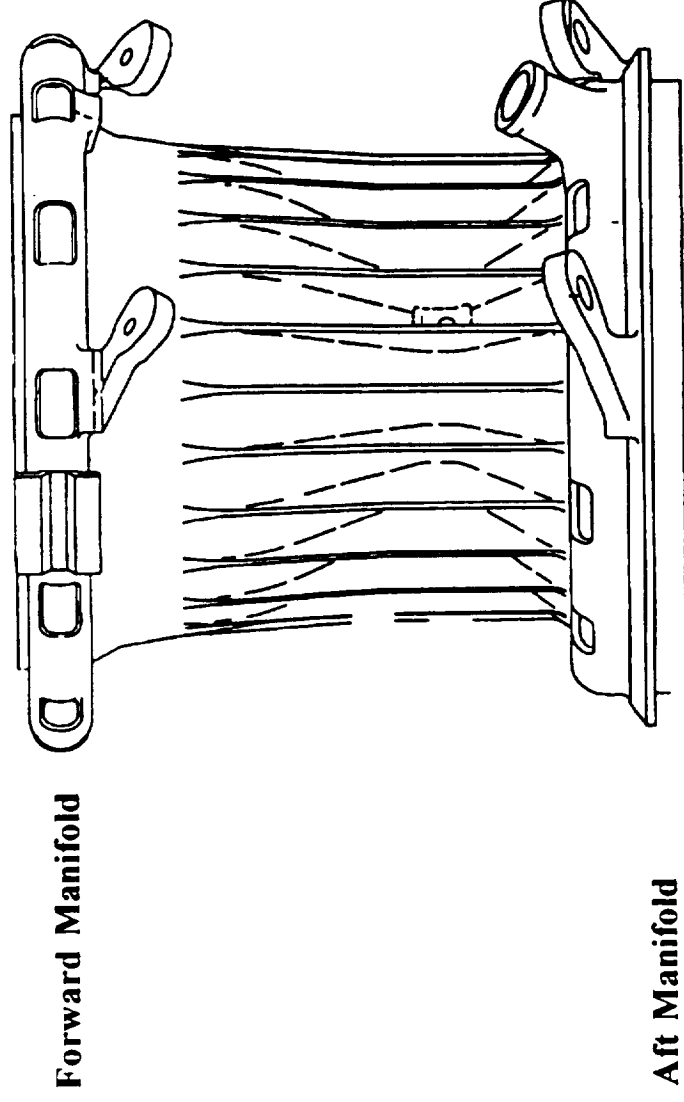


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**NASA**

# MAIN COMBUSTION CHAMBER

P/N 20013



Precision Castparts Corp.

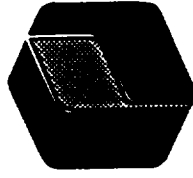
NASA

# **PART ENGINEERING STRATEGY**

---

**JIM HOWCROFT**

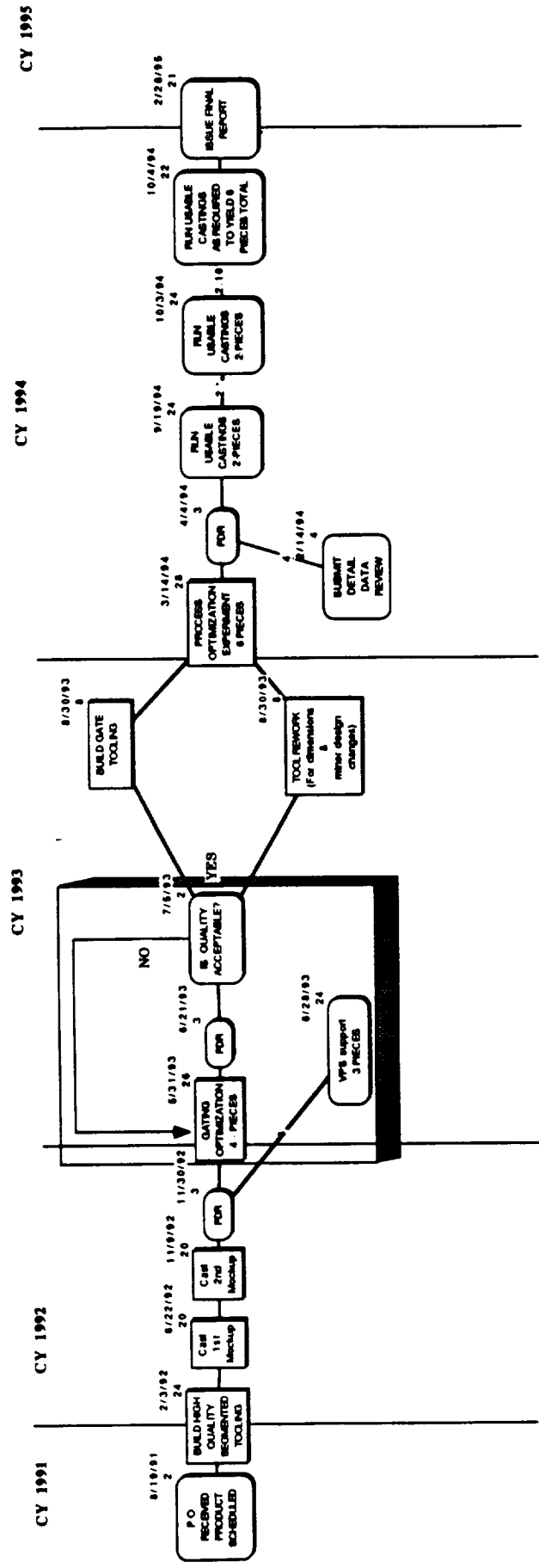
- **STRATEGY FOR GATING DOE LOTS 9, 10, 12 & 14**
- **HOW LESSONS LEARNED FROM DOE WILL BE APPLIED TO FUTURE PARTS**



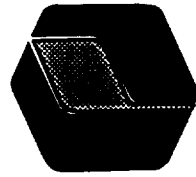
**Precision Castparts Corp.**

**NASA**

# DEVELOPMENT PROCESS



- ENGINEERING SAMPLES
- GATING OPTIMIZATION DOE
- PROCESS SENSITIVITY DOE
- PROTOTYPE PARTS = PROCESS DEMONSTRATION
- ADDITIONAL "BEST EFFORT" CASTING



Precision Castparts Corp.





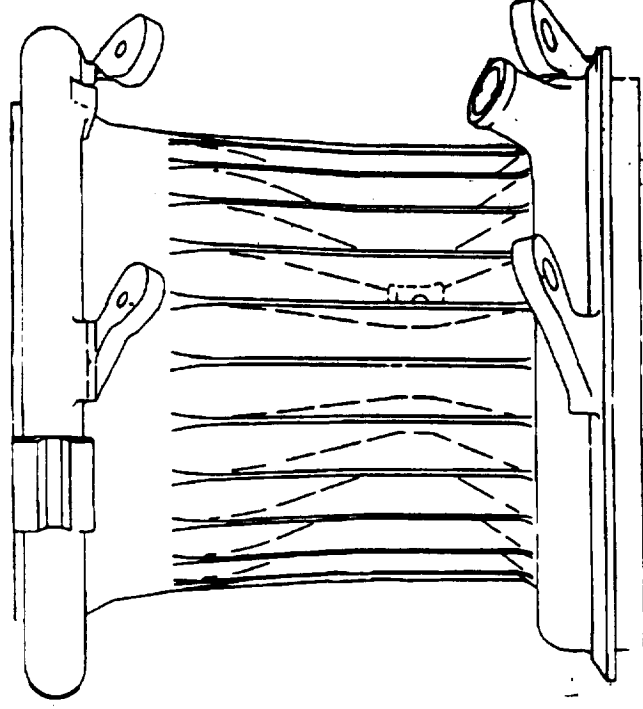
# DESIGN OF EXPERIMENT GATING

---

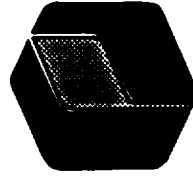
P/N 20013

Lot 009, 010, 012, 014

Alloy JBK 75



**Gating Definition:** The plumbing system through which liquid metal flows to fill and feed the casting during final solidification.



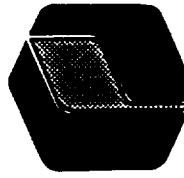
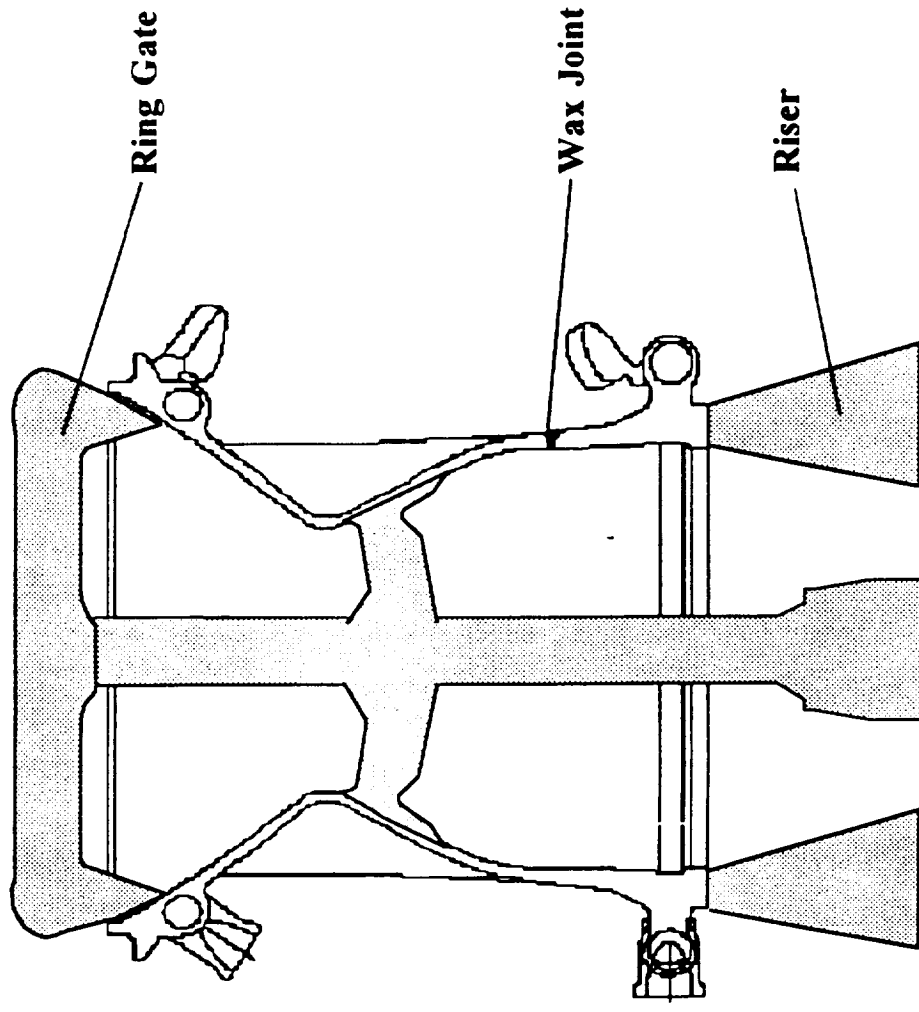
Precision Castparts Corp.

**NASA**

# DESIGN OF EXPERIMENT GATING

Lots 011, 013

SCRAP AT INVESTING



Precision Castparts Corp.

**NASA**

## **CORE GROUP - GATING DOE**

---

### **TEAM MEMBER**

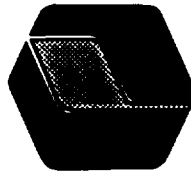
**Jim Howcroft      -      Part Engineer**

### **CONSULTANTS**

**Nancy Dean      -      Metallurgical Engineer**

**Russ Boyles      -      Statistician**

**Jeff Miller      -      Part Engineer**



**Precision Castparts Corp.**

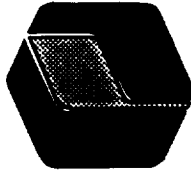


# **DESIGN OF EXPERIMENT GATING**

---

## **CONSIDERATIONS (TREATMENT):**

- **Position of pour**
- **Division of casting**
- **Metal Distribution**
- **Gate location**
- **Gate style**
- **Size/Shape of gates**
- **Thermal gradient control**



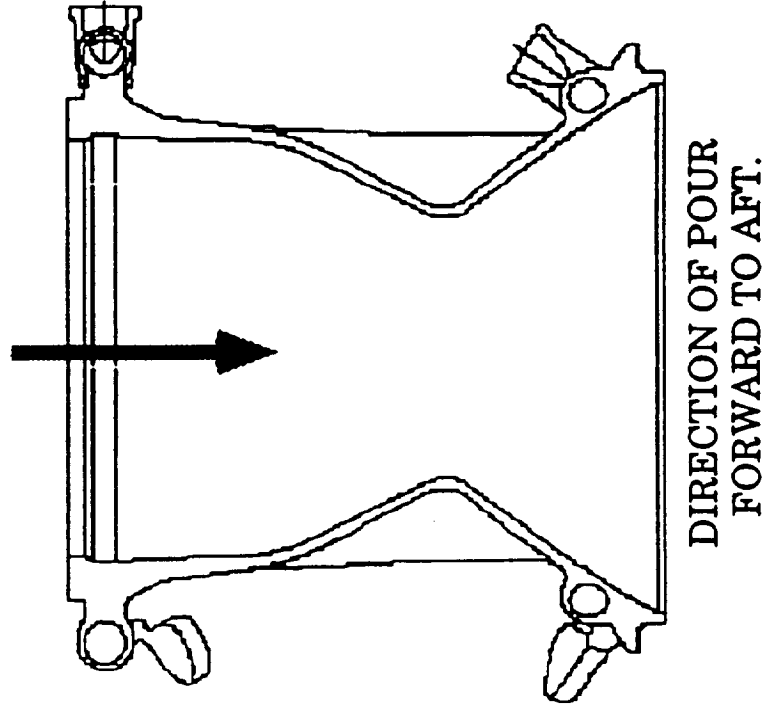
**Precision Castparts Corp.**

**NASA**

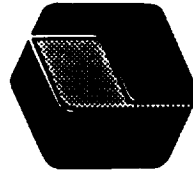
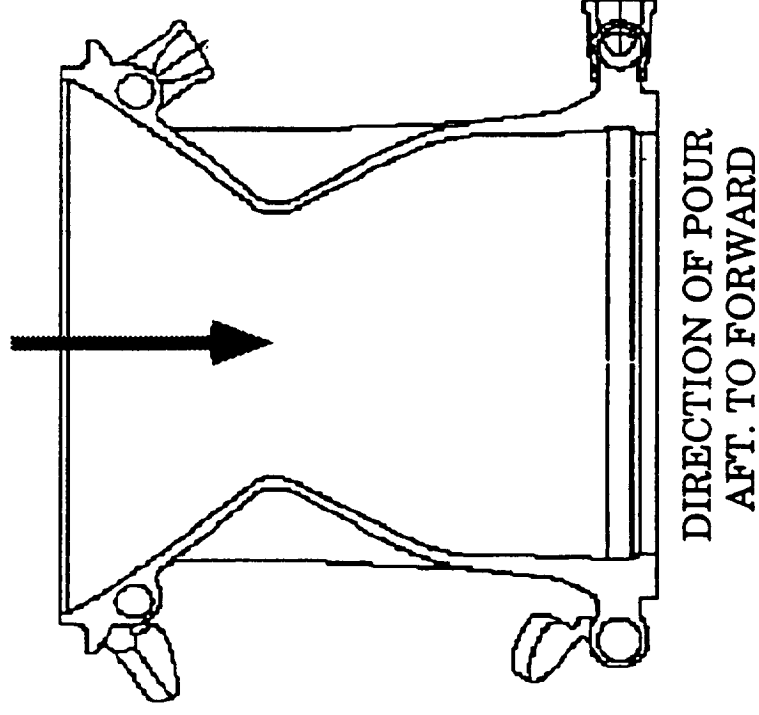
# DESIGN OF EXPERIMENT

## GATING

### POSITION OF POUR -- CASTING



VS.



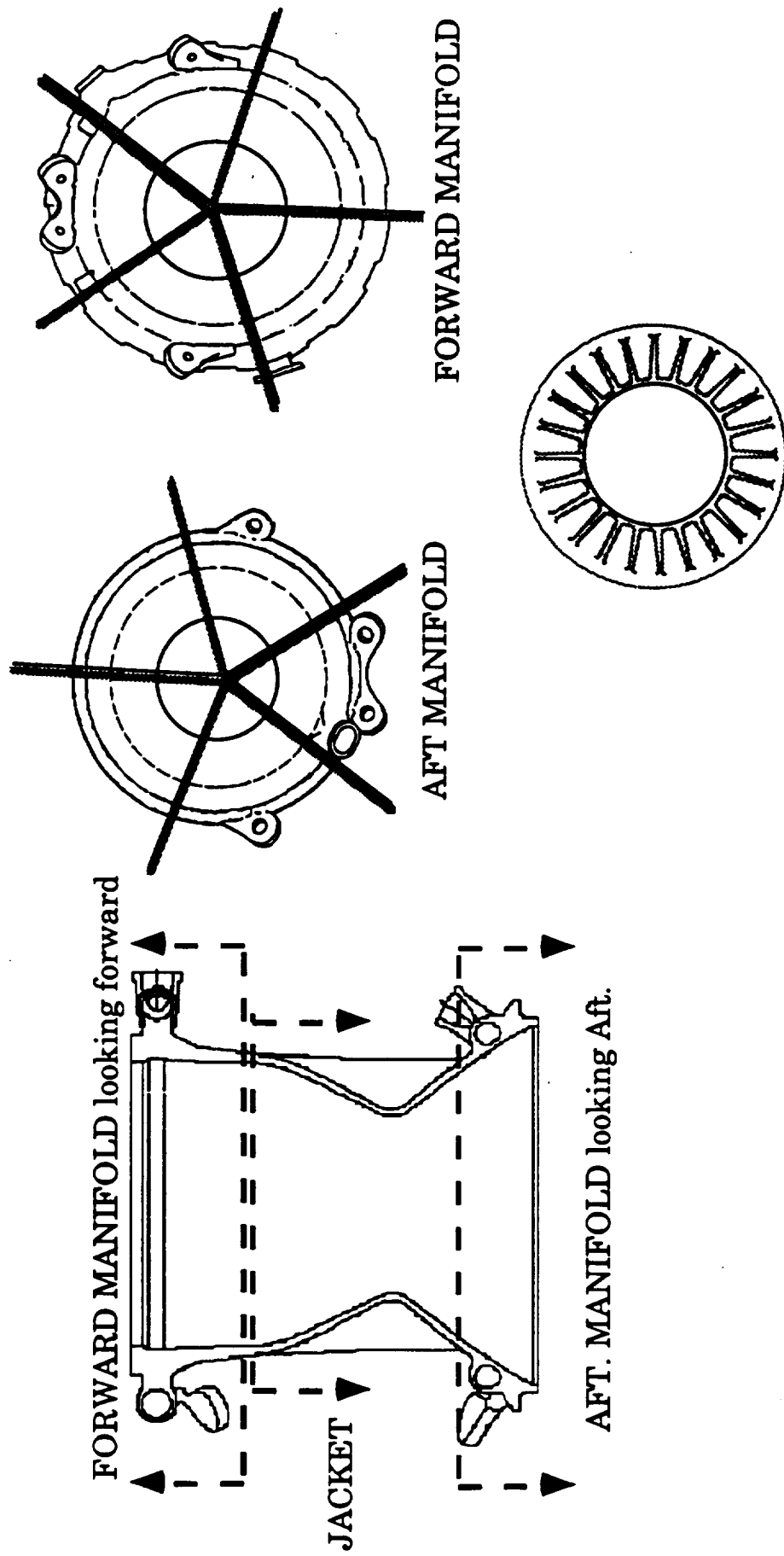
Precision Castparts Corp.

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# DESIGN OF EXPERIMENT

## GATING

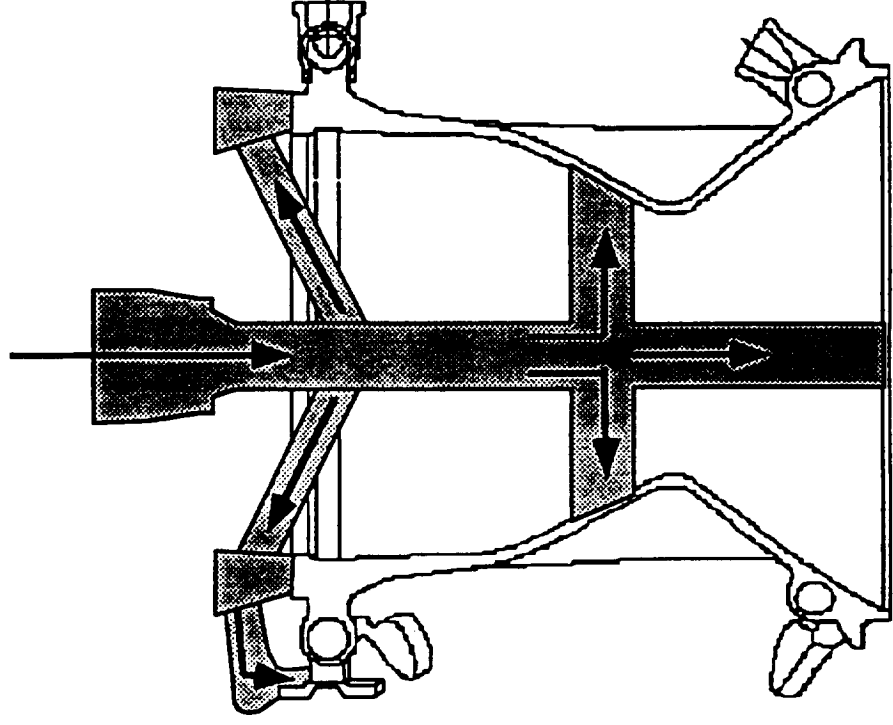
### DIVISION OF CASTING CONFIGURATION



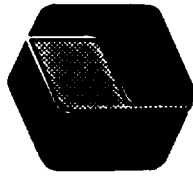
# DESIGN OF EXPERIMENT

## GATING

### METAL DISTRIBUTION



↑ Indicates direction  
metal flows



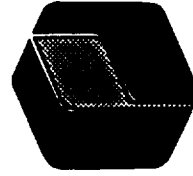
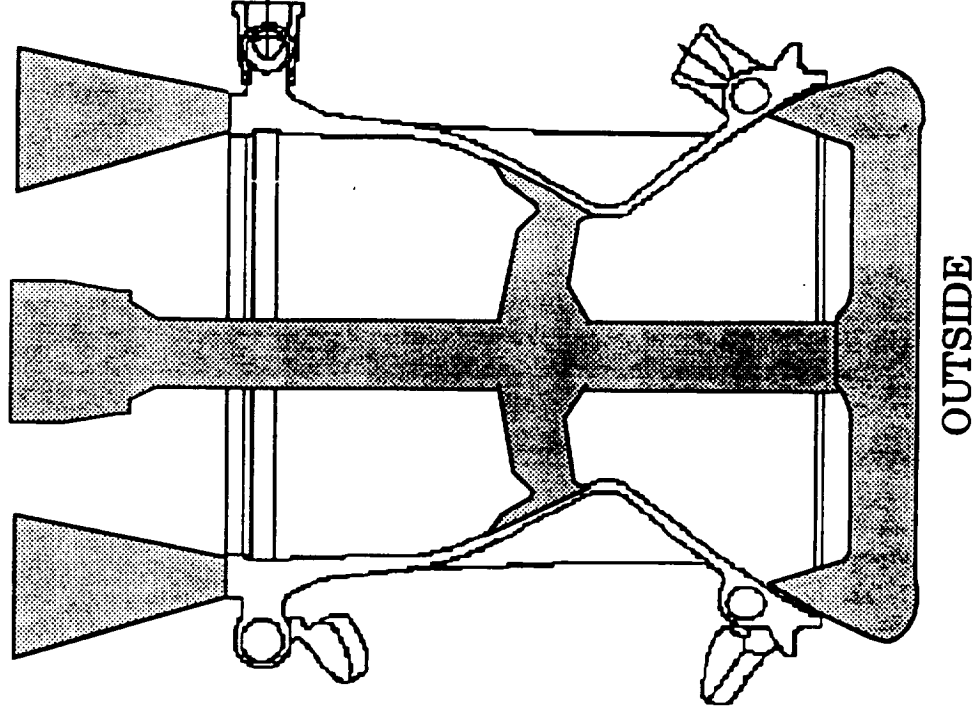
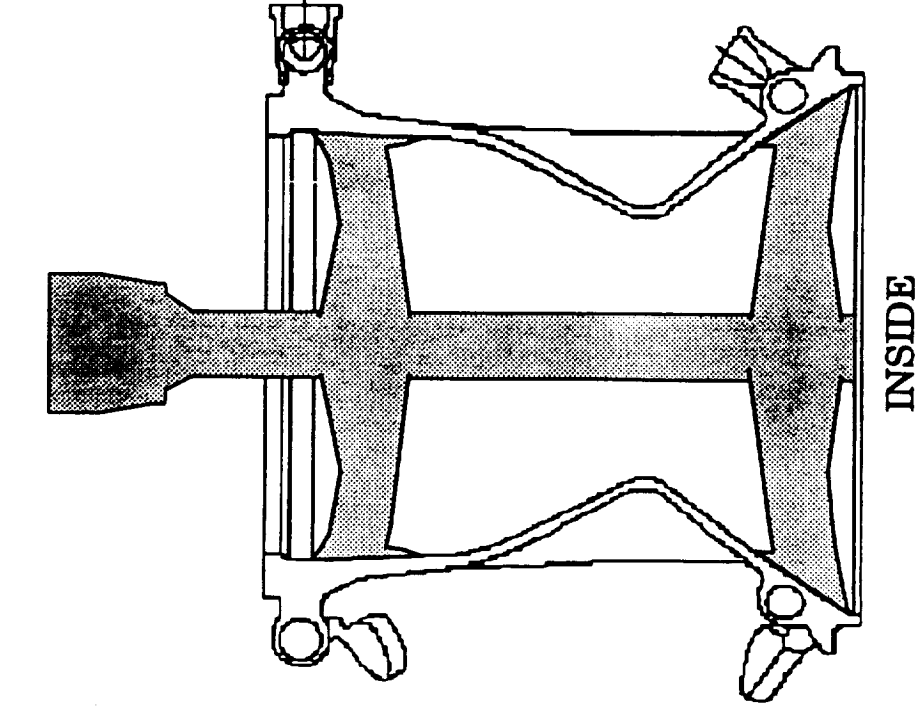
Precision Castparts Corp.

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# DESIGN OF EXPERIMENT

## GATING

### GATE LOCATION



Precision Castparts Corp.

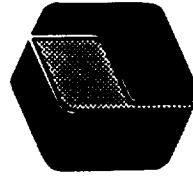
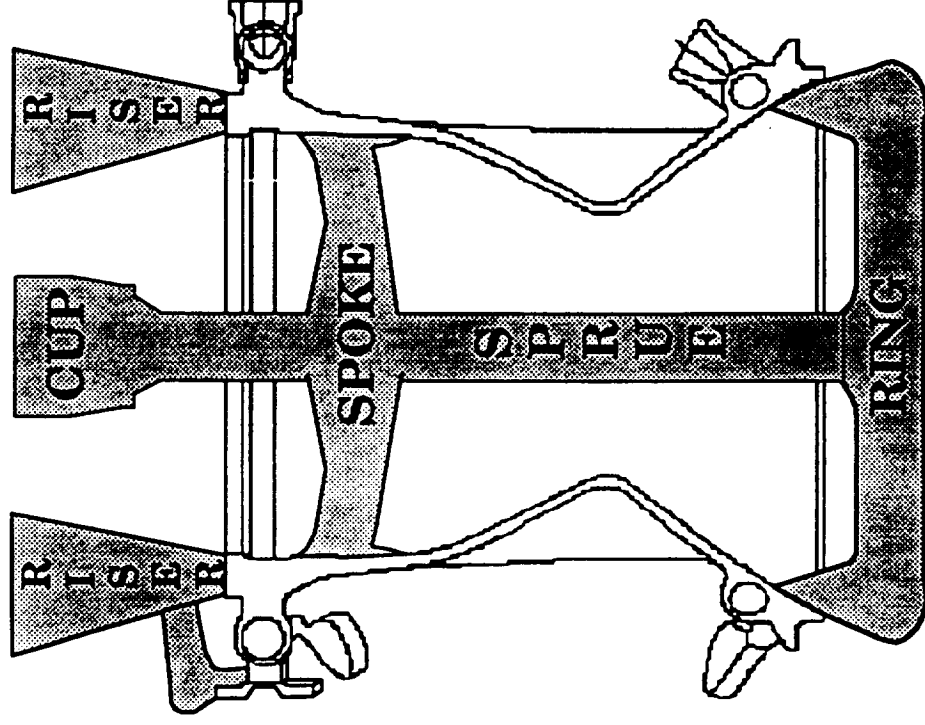
**NASA**



# DESIGN OF EXPERIMENT

## GATING

### GATING STYLE



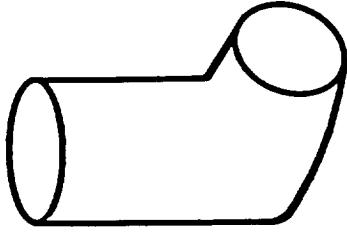
Precision Castparts Corp.

NASA

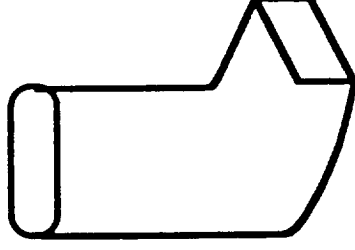
# DESIGN OF EXPERIMENT

## GATING

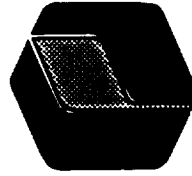
### SIZE/SHAPE OF GATES



ROUND



SQUARE



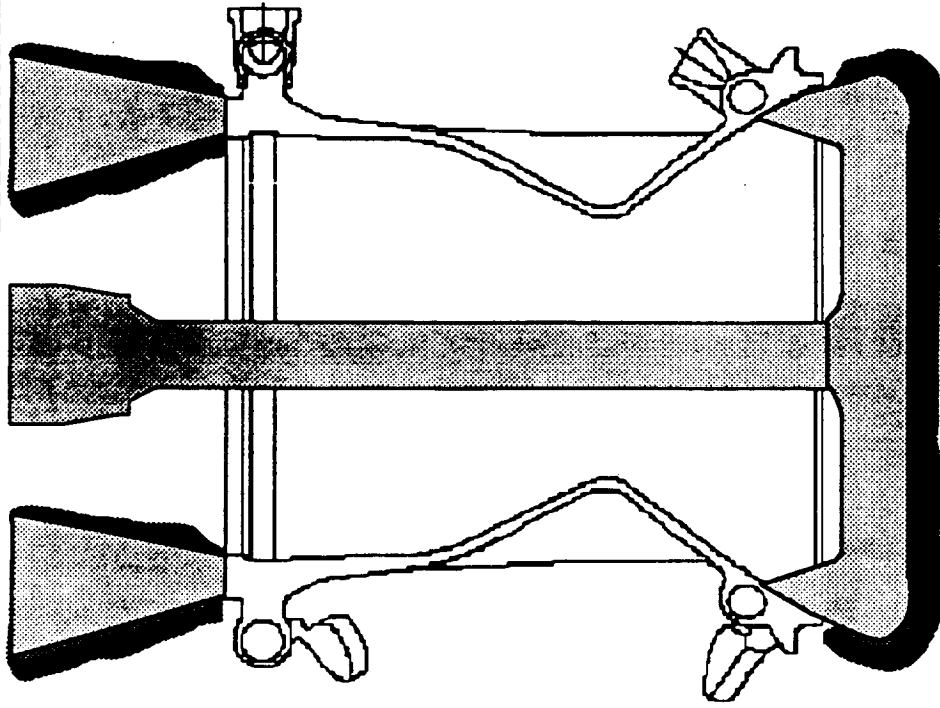
Precision Castparts Corp.

NASA

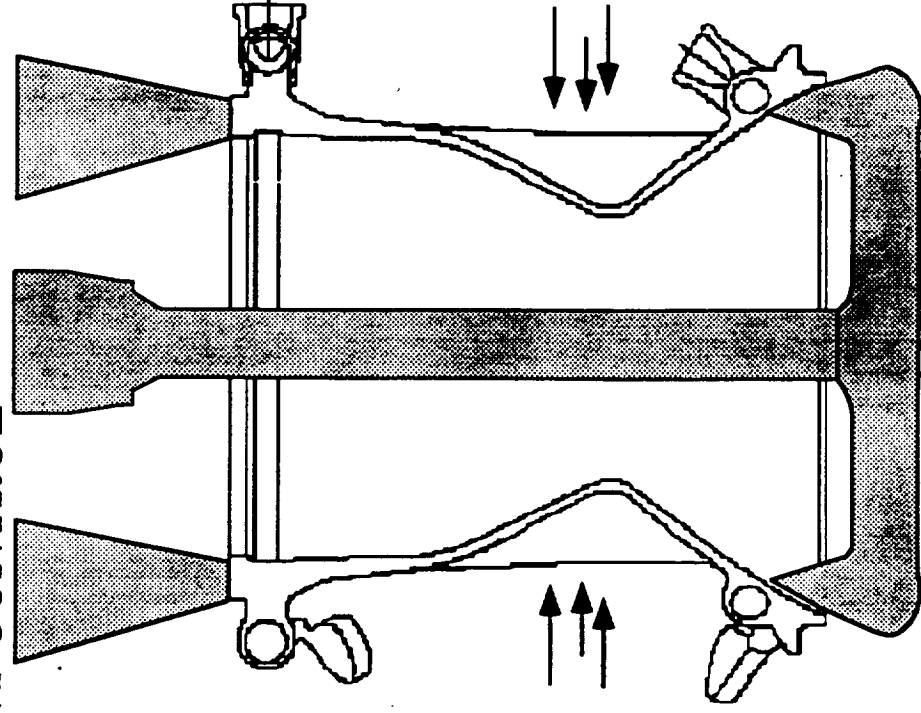
# DESIGN OF EXPERIMENT

## GATING

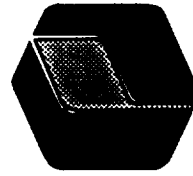
### THERMAL GRADIENT CONTROL



CONTROL HEAT LOSS INSULATION



INFLUENCE HEAT LOSS BY ALTERNATE MEANS



Precision Castparts Corp.

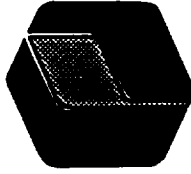


# DESIGN OF EXPERIMENT

## GATING

### METHODS TO BE USED TO EVALUATE RESULTS:

- Visual -- White Light
- Fluorescent Penetrant -- Black Light
- Radiographic -- X-Ray
- Chemical Mill -- Acid Bath
- Metallography -- Selective Section Cutup/ Mount & Polish/  
Examine



Precision Castparts Corp.

**NASA**

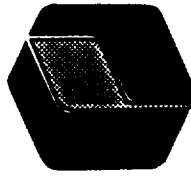
# **DIMENSIONAL RESULTS OF GATING DOE**

**Lots 9 - 14**

---

**JOHN DAVIS**

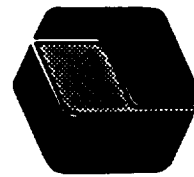
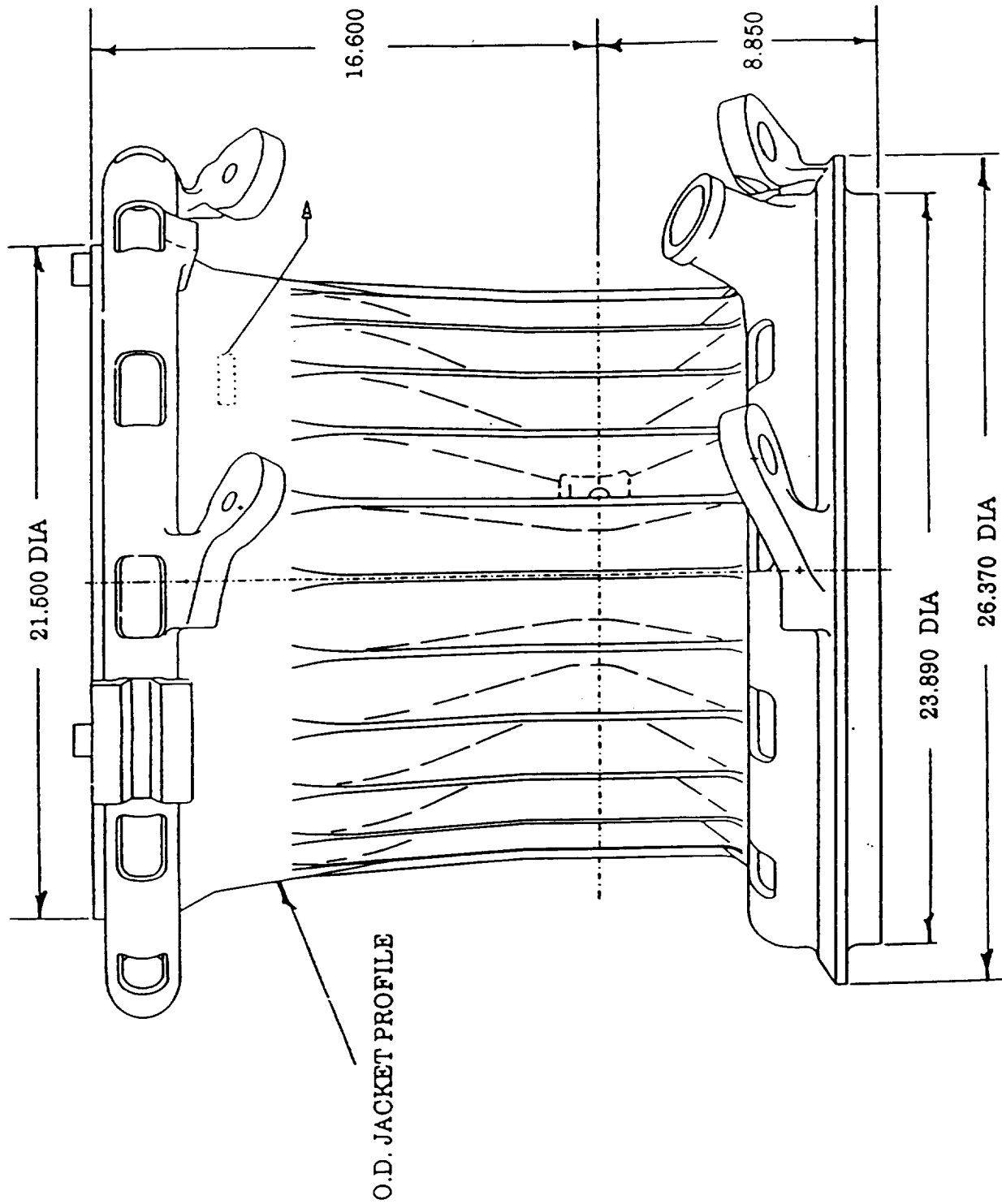
- **Gating DOE variations did not hurt Dimensional integrity of part.**
- **One piece tool for jacket would tighten down spread caused by assembly.**



**Precision Castparts Corp.**

**NASA**

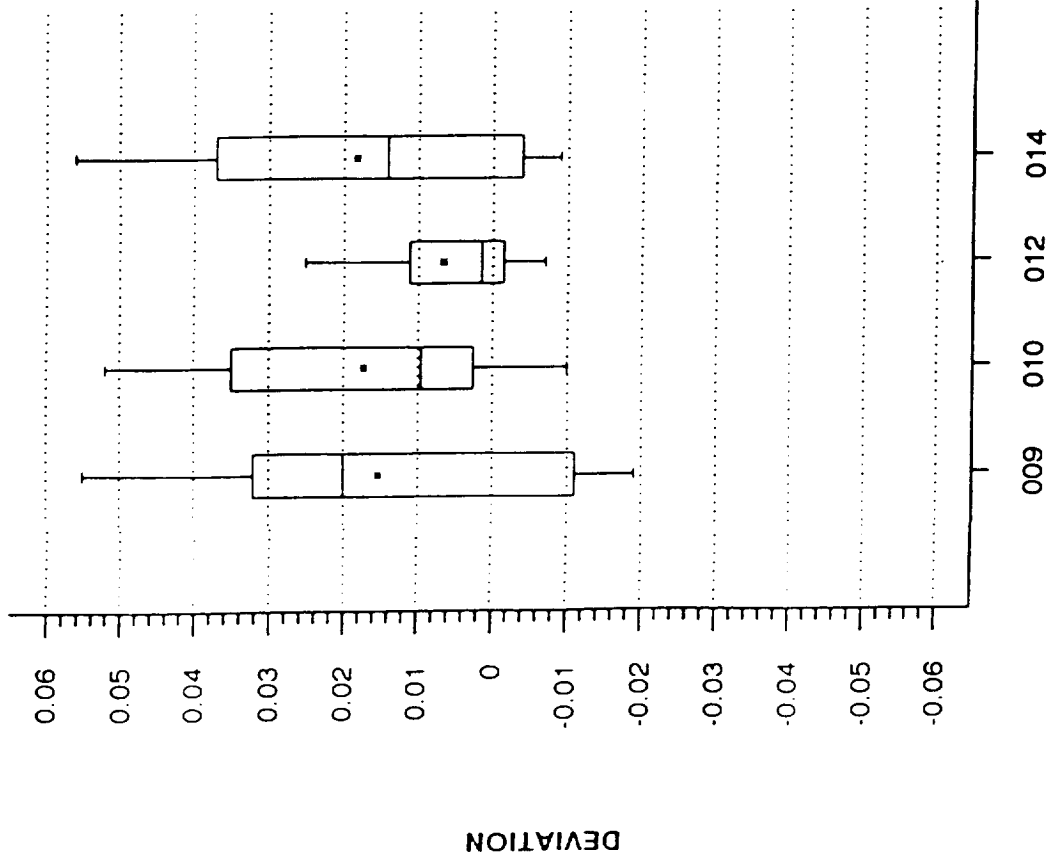
# NASA AMCC BLUEPRINT DIMENSIONS



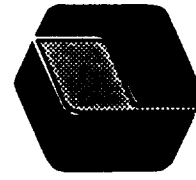
Precision Castparts Corp.

NASA

Multiple Box-and-Whisker Plot  
FORWARD FLANGE TO -A- 16.600

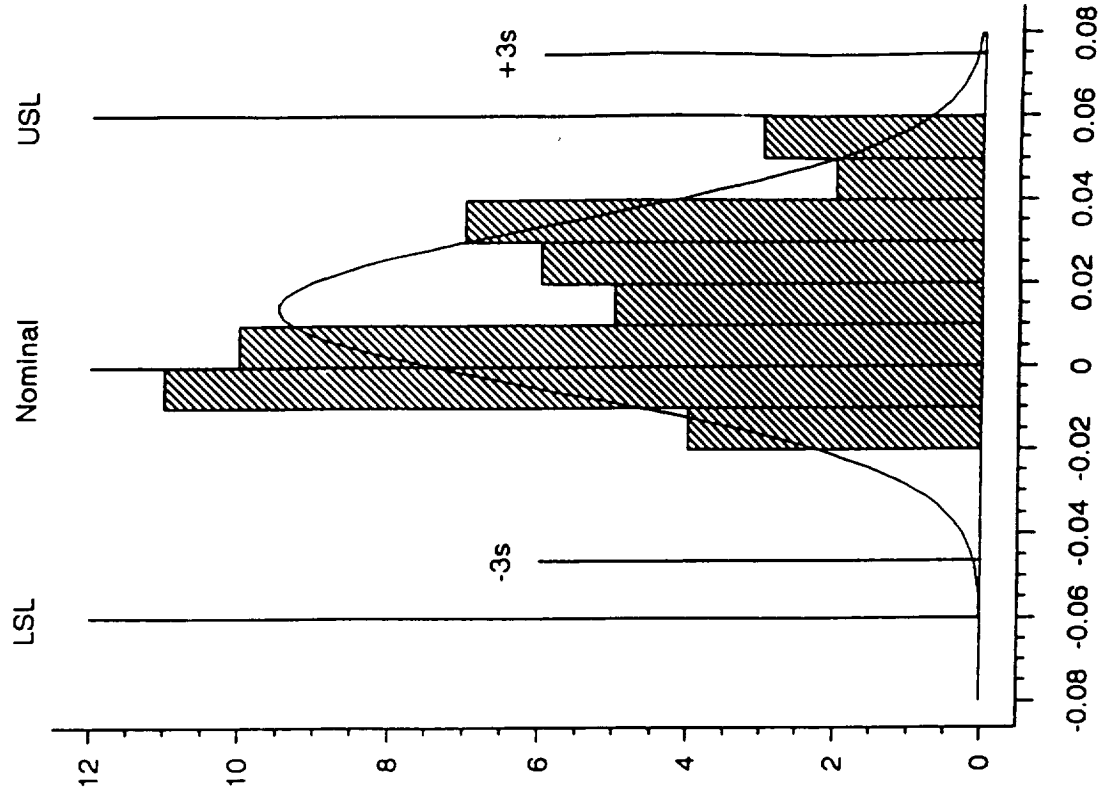


SERIAL NUMBER



Precision Castparts Corp.

Process Capability: SN 9,10,12,14



FORWARD FLANGE TO -A- 16.600



# PROCESS CAPABILITY ANALYSIS

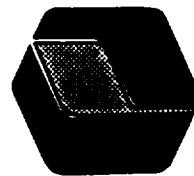
## FORWARD FLANGE TO -A- 16.600

FWD FLANGE TO -A- 16.600 (SN 1-5, 7)

Specification:		Normal distribution:		6.0 sigma limits:	
Upper	0.06	Count	72	+3.0 sigma	0.0633
Nominal	0	Mean	0.006	Mean	0.006
Lower	-0.06	Sigma	0.0191	-3.0 sigma	-0.0513
Observed beyond spec.:		Estimated beyond spec.:		Capability indices:	
High	0.000 %	High	0.235 %	CP	1.04712
Low	0.000 %	Low	0.027 %	CR	0.955
-----		-----		CPK	0.942408
Total	0.000 %	Total	0.262 %	(upper)	0.942408
				(lower)	1.15183
				K	0.1
				CPM	0.996689

FWD FLANGE TO -A- 16.600 (SN 9,10,12,14)

Specification:		Normal distribution:		6.0 sigma limits:	
Upper	0.06	Count	48	+3.0 sigma	0.0749
Nominal	0	Mean	0.0143	Mean	0.0143
Lower	-0.06	Sigma	0.0202	-3.0 sigma	-0.0463
Observed beyond spec.:		Estimated beyond spec.:		Capability indices:	
High	0.000 %	High	1.184 %	CP	0.990099
Low	0.000 %	Low	0.012 %	CR	1.01
-----		-----		CPK	0.754125
Total	0.000 %	Total	1.195 %	(upper)	0.754125
				(lower)	1.22607
				K	0.238333
				CPM	0.806883



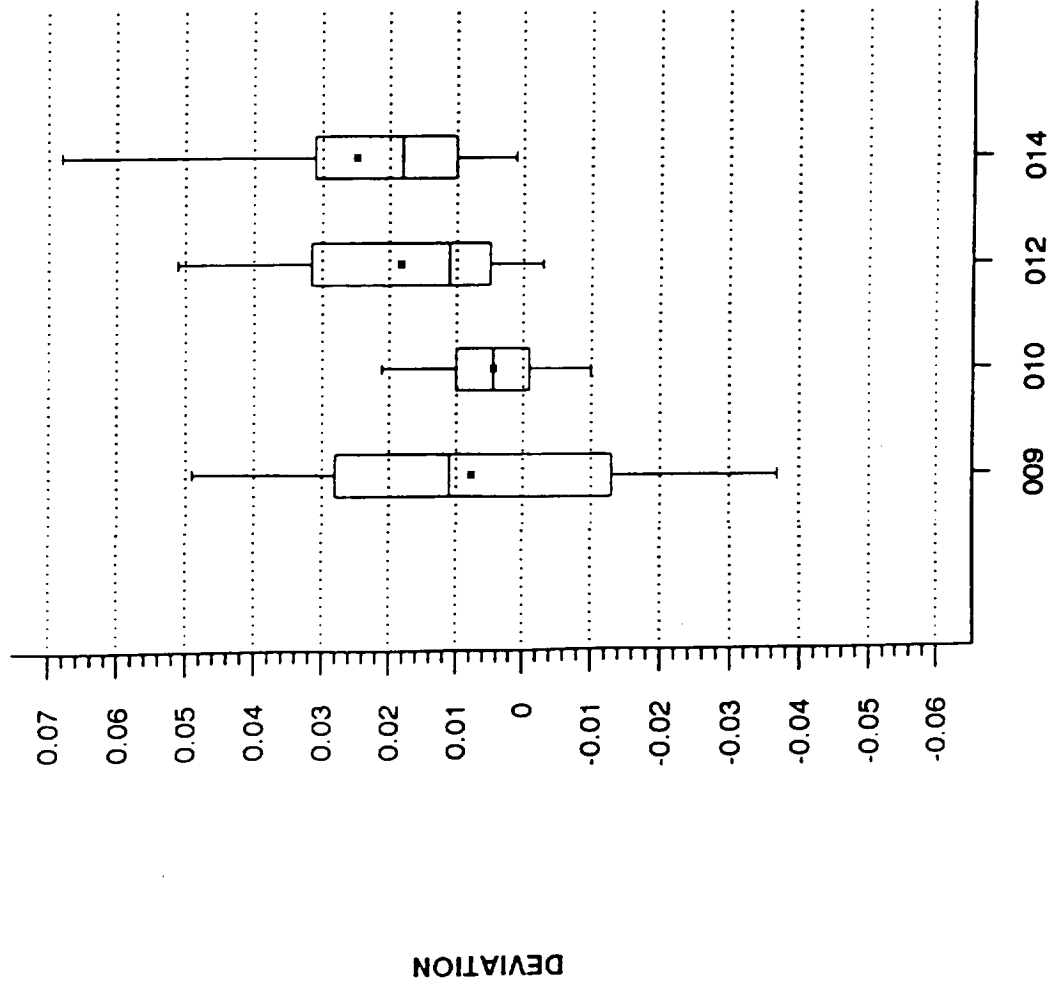
Precision Castparts Corp.

NASA

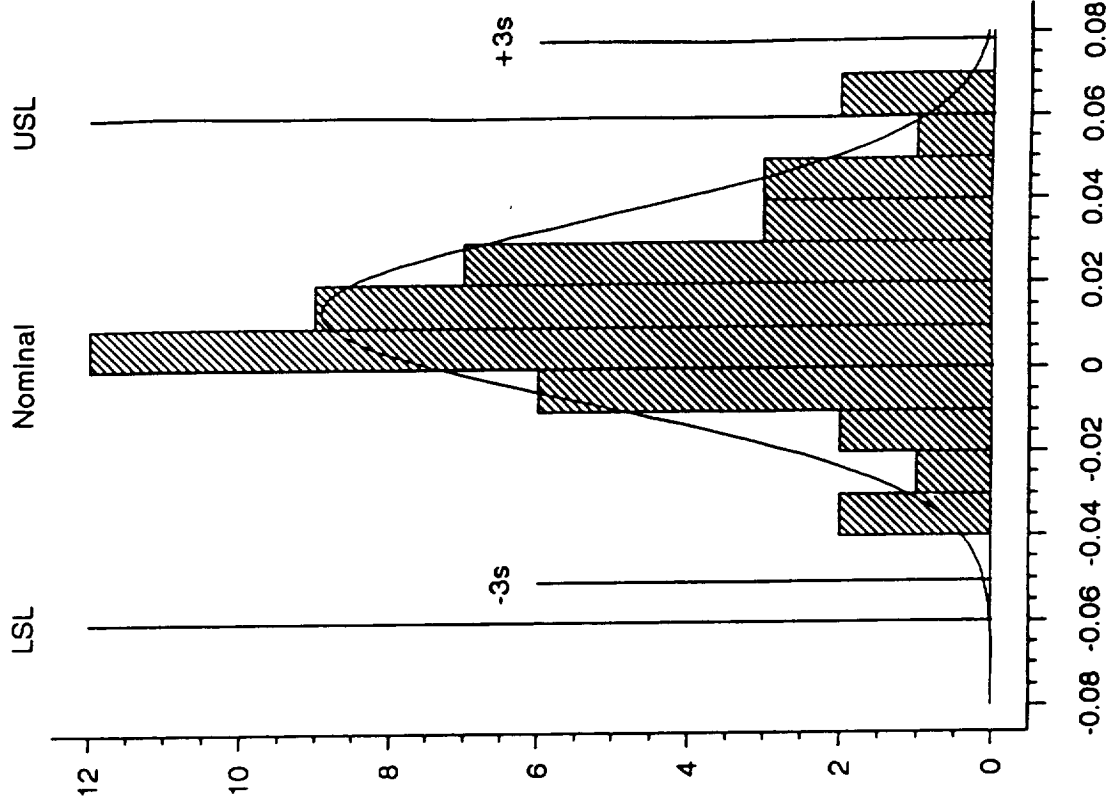


# Multiple Box-and-Whisker Plot

AFT FLANGE TO -A- 8.850



# Process Capability: SN 9,10,12,14



Precision Castparts Corp.

AFT FLANGE TO -A- 8.850



# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE TO -A- 8.850

AFT FLANGE TO -A- 8.850 (SN 1-5, 7)

Specification: Upper 0.06  
Nominal 0  
Lower -0.06

Normal distribution: Count 72  
Mean 0.0072  
Sigma 0.016

6.0 sigma limits:  
+3.0 sigma 0.0552  
Mean 0.0072  
-3.0 sigma -0.0408

Observed beyond spec.: High 0.000 %  
Low 0.000 %  
-----  
Total 0.000 %

Estimated beyond spec.: High 0.048 %  
Low 0.001 %  
-----  
Total 0.050 %

Capability indices: CP 1.25  
CR 0.8  
CPK 1.1  
(upper) 1.1  
(lower) 1.4  
K 0.12  
CPM 1.14015

AFT FLANGE TO -A- 8.850 (SN 9,10,12,14)

Specification: Upper 0.06  
Nominal 0  
Lower -0.06

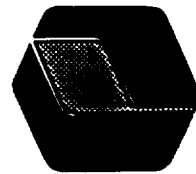
Normal distribution: Count 48  
Mean 0.0138  
Sigma 0.0215

6.0 sigma limits:  
+3.0 sigma 0.0783  
Mean 0.0138  
-3.0 sigma -0.0507

Observed beyond spec.: High 4.167 %  
Low 0.000 %  
-----  
Total 4.167 %

Estimated beyond spec.: High 1.582 %  
Low 0.030 %  
-----  
Total 1.612 %

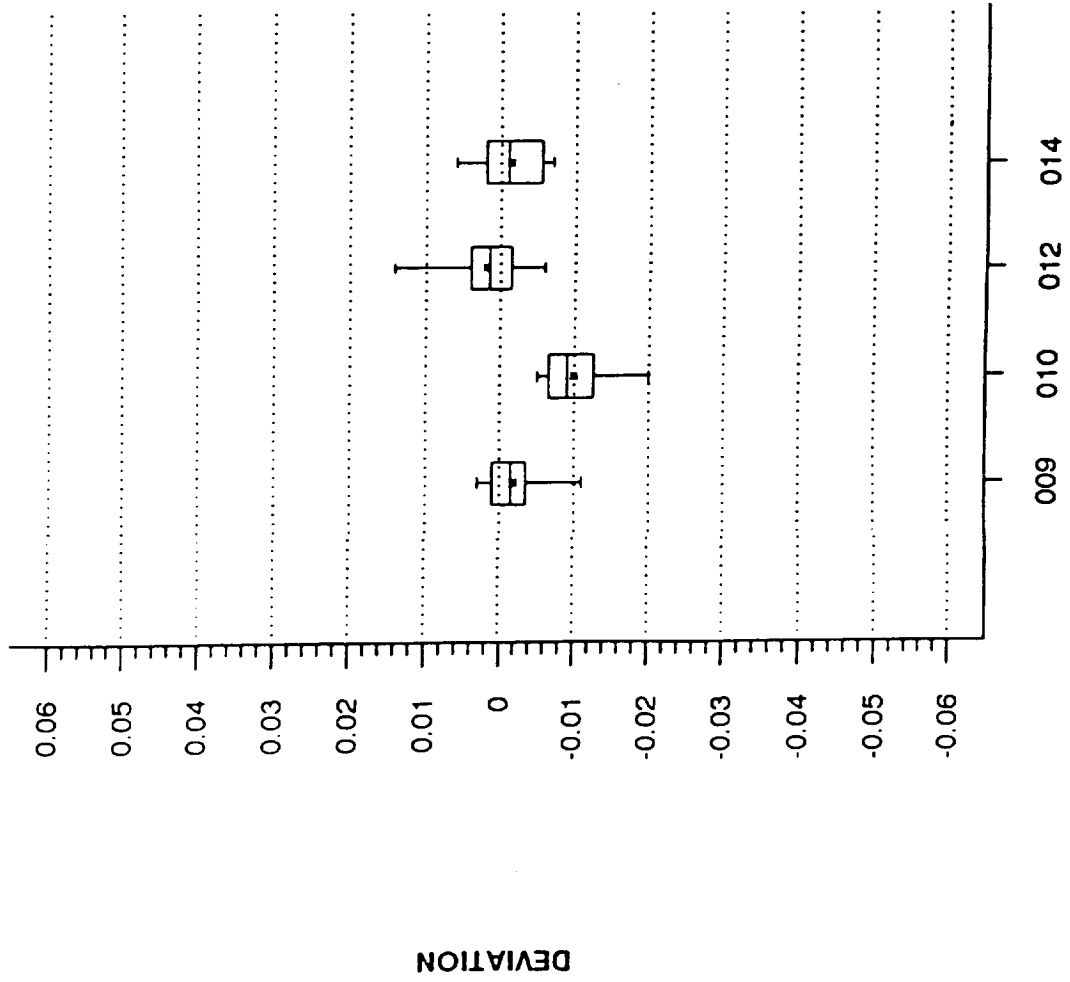
Capability indices: CP 0.930233  
CR 1.075  
CPK 0.716279  
(upper) 0.716279  
(lower) 1.14419  
K 0.23  
CPM 0.782418



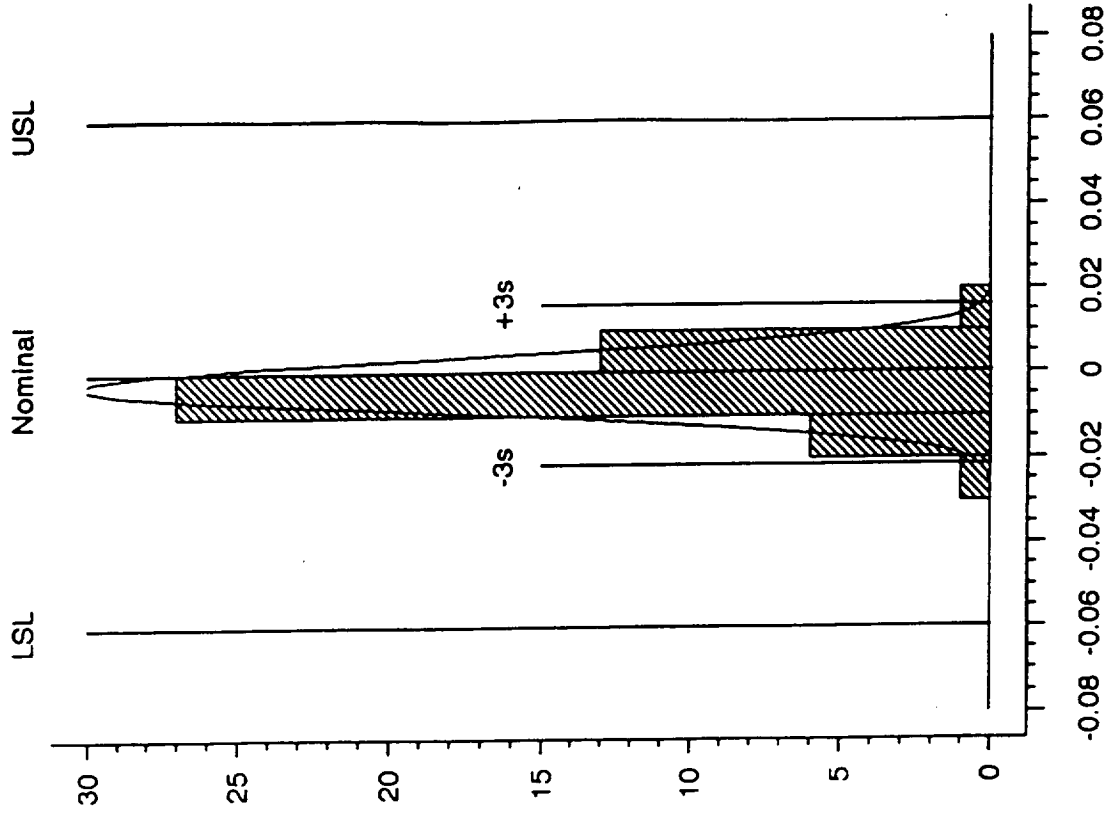
Precision Castparts Corp.

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Multiple Box-and-Whisker Plot  
FORWARD FLANGE DIA 21.500



Process Capability: SN 9,10,12,14



# PROCESS CAPABILITY ANALYSIS FORWARD FLANGE DIA 21.500

FWD FLANGE DIA 21.500 (SN 1-5, 7)

Specification: Upper 0.06  
Nominal 0  
Lower -0.06

Normal distribution: Count 72  
Mean -0.0039  
Sigma 0.0166

6.0 sigma limits: +3.0 sigma 0.0459  
Mean -0.0039  
-3.0 sigma -0.0537

Observed beyond spec.: High 0.000 %  
Low 0.000 %  
Total 0.000 %

Estimated beyond spec.: High 0.006 %  
Low 0.036 %  
Total 0.042 %

Capability indices: CP 1.20482  
CR 0.83  
CPK 1.12651  
(upper) 1.28313  
(lower) 1.12651  
K -0.065  
CPM 1.17106

FWD FLANGE DIA 21.500 (SN 9,10,12,14)

Specification: Upper 0.06  
Nominal 0  
Lower -0.06

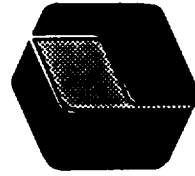
Normal distribution: Count 48  
Mean -0.0028  
Sigma 0.0063

6.0 sigma limits: +3.0 sigma 0.0161  
Mean -0.0028  
-3.0 sigma -0.0217

Observed beyond spec.: High 0.000 %  
Low 0.000 %  
Total 0.000 %

Estimated beyond spec.: High 0.000 %  
Low 0.000 %  
Total 0.000 %

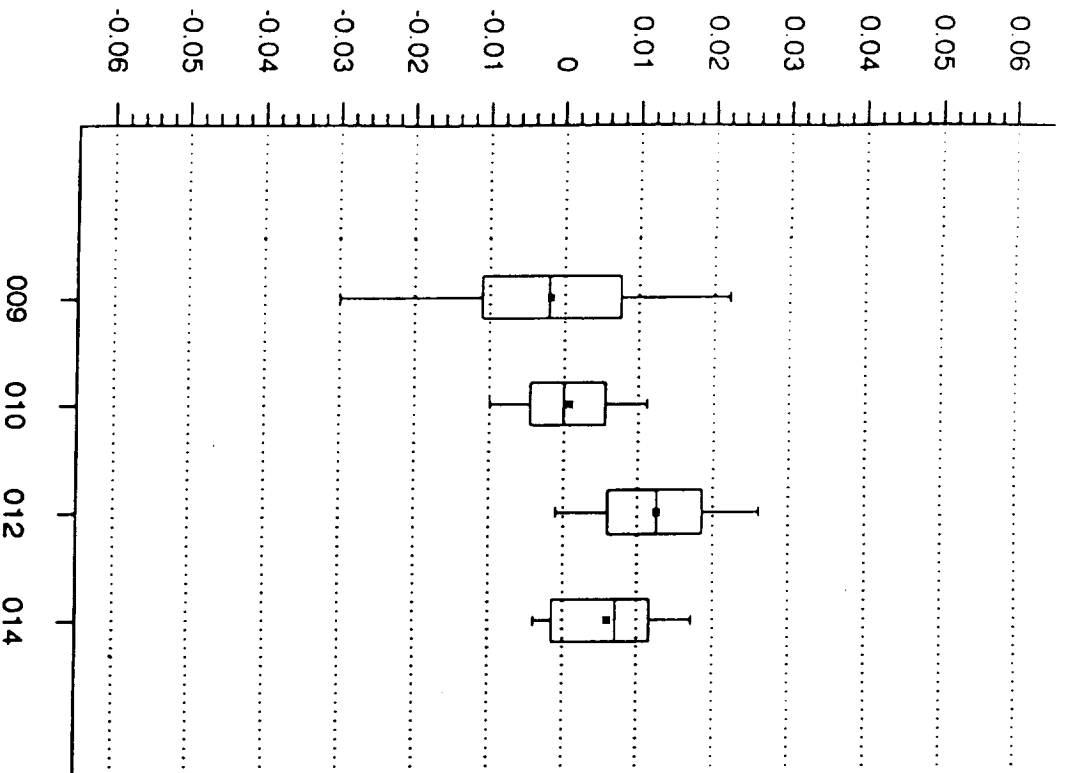
Capability indices: CP 3.1746  
CR 0.315  
CPK 3.02646  
(upper) 3.32275  
(lower) 3.02646  
K -0.0466667  
CPM 2.89834



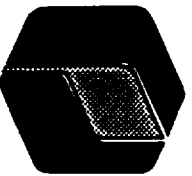
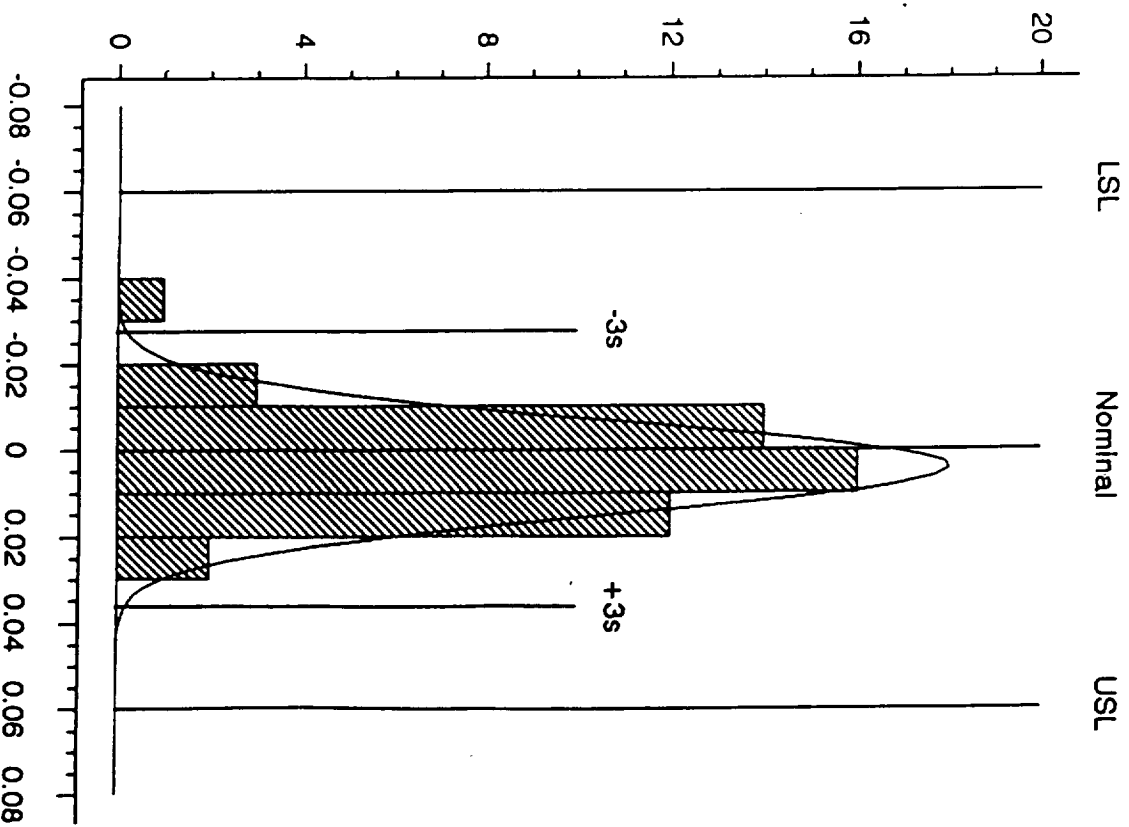
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# Multiple Box-and-Whisker Plot AFT FLANGE DIA 26.370



# Process Capability: SN 9,10,12,14



Precision Castparts Corp.



# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE DIA 26.370

AFT FLANGE DIA 26.370 (SN 1-5, 7)

Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 72	+3.0 sigma 0.0563
Nominal 0	Mean 0.0023	Mean 0.0023
Lower -0.06	Sigma 0.018	-3.0 sigma -0.0517

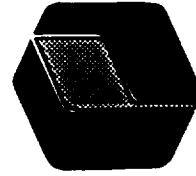
Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 0.000 %	High 0.067 %	CP 1.1111
Low 0.000 %	Low 0.027 %	CR 0.9
-----	-----	CPK 1.06852
Total 0.000 %	Total 0.094 %	(upper) 1.06852
		(lower) 1.1537
		K 0.0383333
		CPM 1.10434

AFT FLANGE DIA 26.370 (SN 9,10,12,14)

Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 48	+3.0 sigma 0.0361
Nominal 0	Mean 0.0043	Mean 0.0043
Lower -0.06	Sigma 0.0106	-3.0 sigma -0.0275

Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 0.000 %	High 0.000 %	CP 1.88679
Low 0.000 %	Low 0.000 %	CR 0.53
-----	-----	CPK 1.75157
Total 0.000 %	Total 0.000 %	(upper) 1.75157
		(lower) 2.02201
		K 0.0716667
		CPM 1.7398

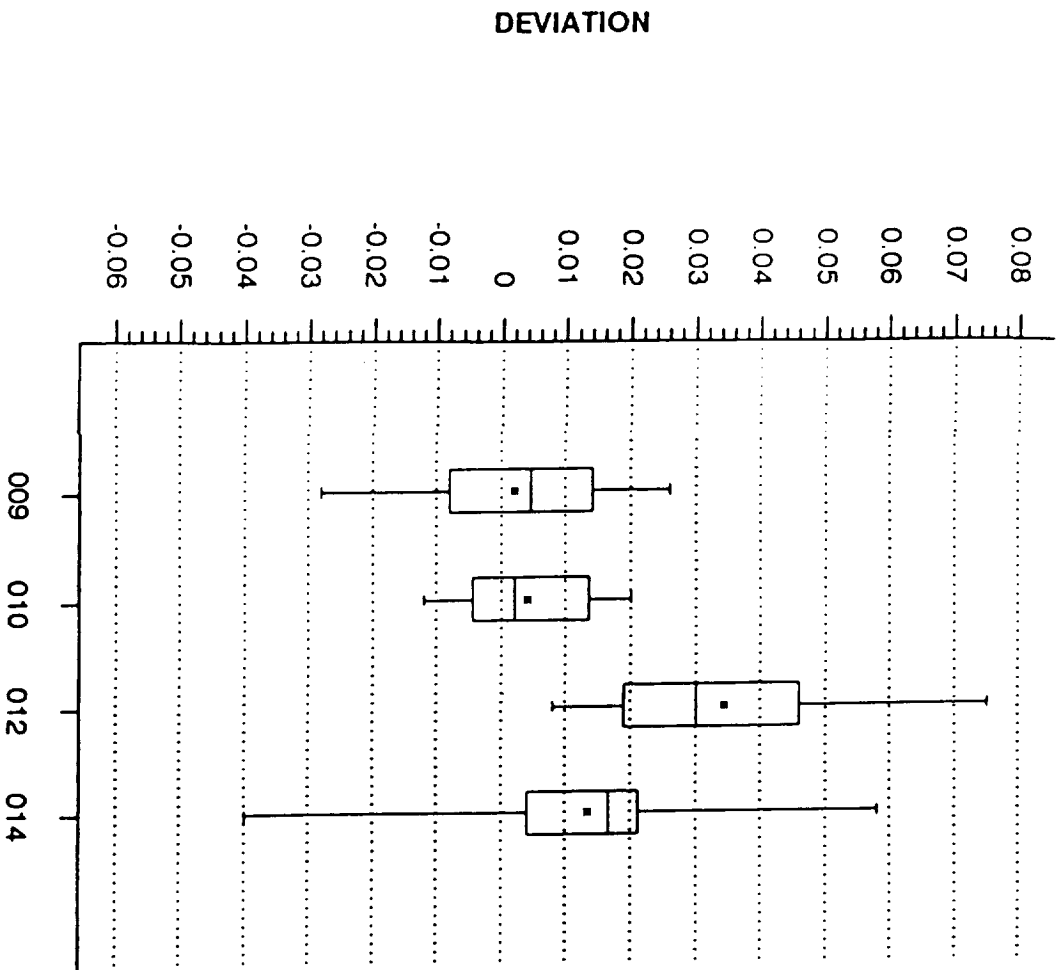


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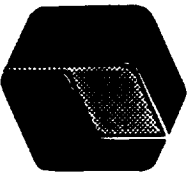
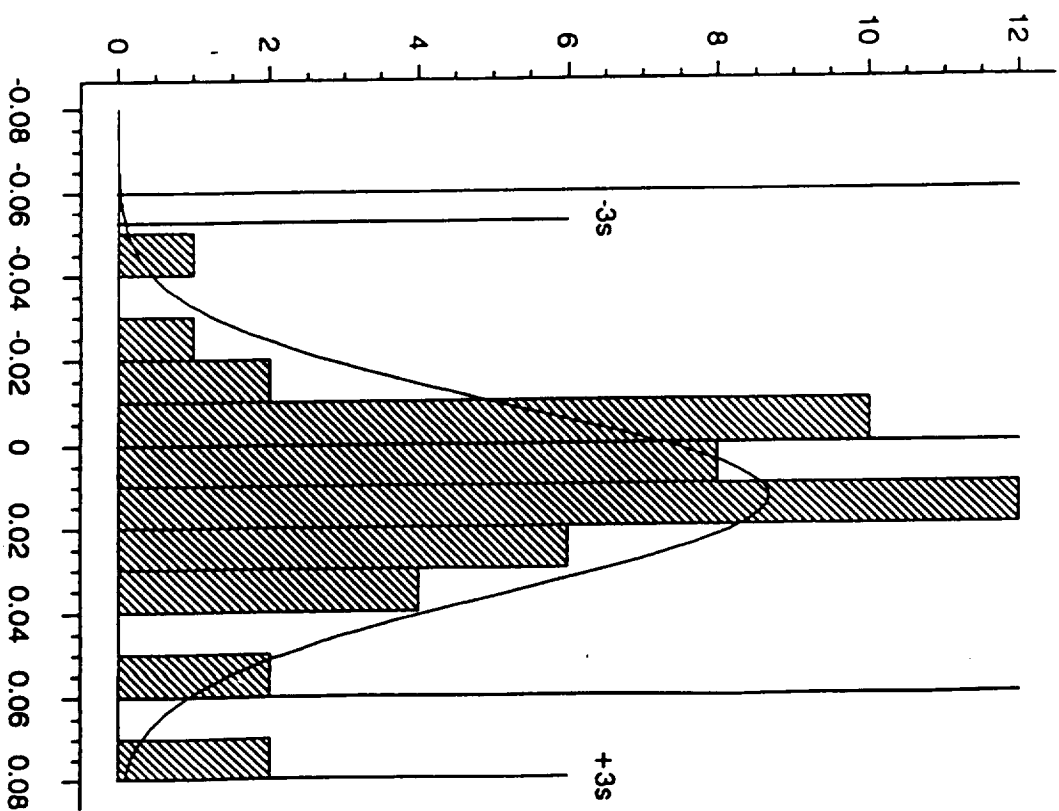
NASA

# Multiple Box-and-Whisker Plot

## AFT FLANGE DIA 23.890



# Process Capability: SN 9,10,12,14



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# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE DIA 23.890

AFT FLANGE DIA 23.890 (SN 1-5, 7)

Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 72	+3.0 sigma 0.0635
Nominal 0	Mean 0.0101	Mean 0.0101
Lower -0.06	Sigma 0.0178	-3.0 sigma -0.0433

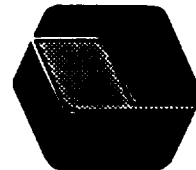
Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 0.000 %	High 0.253 %	CP 1.1236
Low 0.000 %	Low 0.004 %	CR 0.89
-----	-----	CPK 0.934457
Total 0.000 %	Total 0.257 %	(upper) 0.934457
		(lower) 1.31273
		K 0.168333
		CPM 0.975312

AFT FLANGE DIA 23.890 (SN 9,10,12,14)

Specification:	Normal distribution:	6.0 sigma limits:
Upper 0.06	Count 48	+3.0 sigma 0.0798
Nominal 0	Mean 0.0135	Mean 0.0135
Lower -0.06	Sigma 0.0221	-3.0 sigma -0.0528

Observed beyond spec.:	Estimated beyond spec.:	Capability indices:
High 4.167 %	High 1.769 %	CP 0.904977
Low 0.000 %	Low 0.044 %	CR 1.105
-----	-----	CPK 0.701357
Total 4.167 %	Total 1.813 %	(upper) 0.701357
		(lower) 1.1086
		K 0.225
		CPM 0.771505



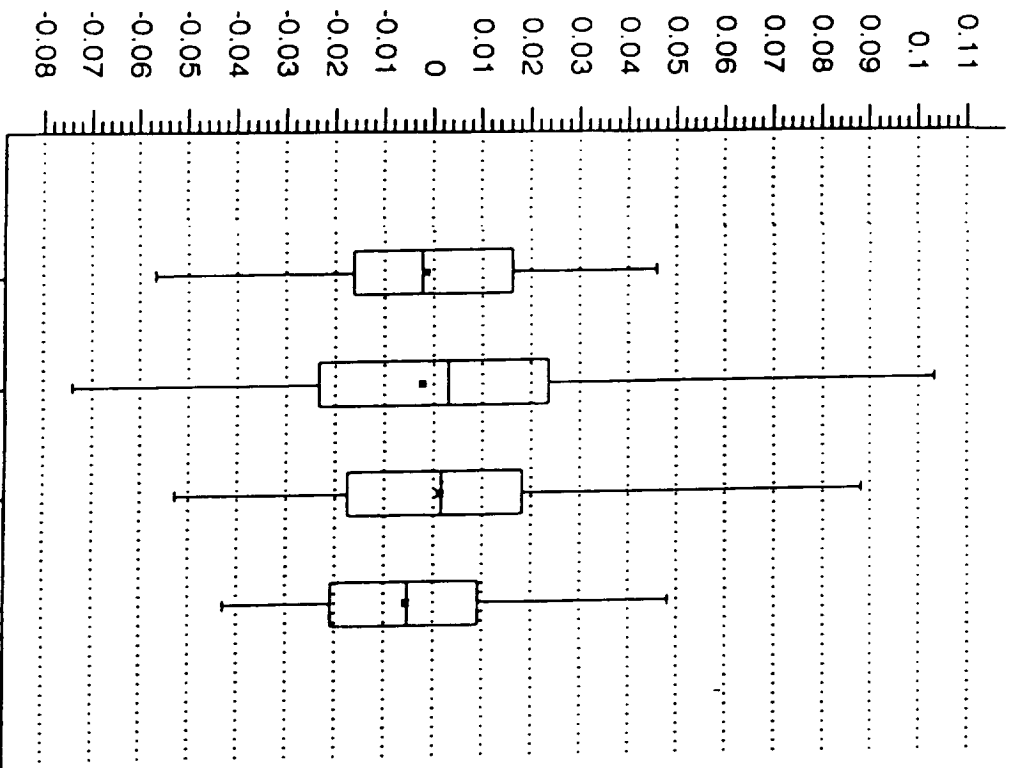
Precision Castparts Corp.

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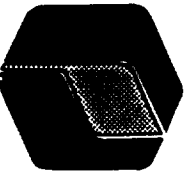
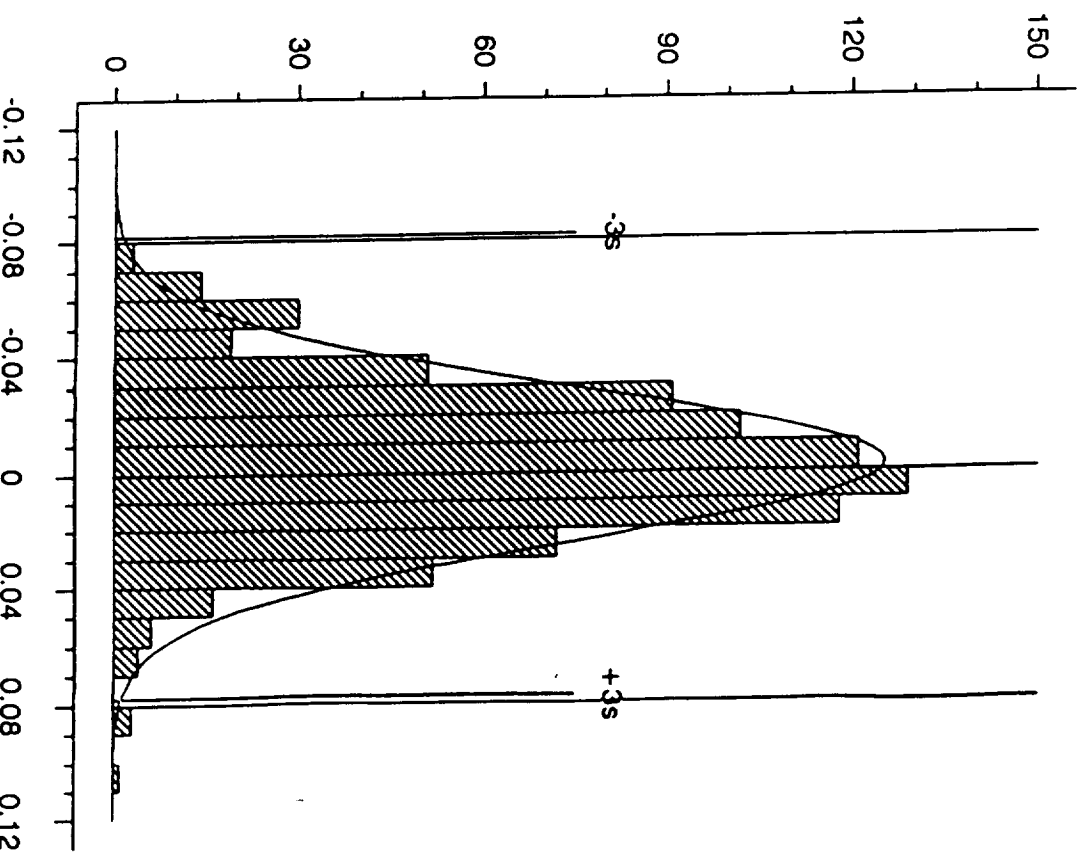
# Multiple Box-and-Whisker Plot OUTSIDE JACKET PROFILE 0.160 TO ABC

SERIAL NUMBER



Process Capability: SN 9,10,12,14

LSL Nominal USL



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# PROCESS CAPABILITY ANALYSIS

## OD JACKET PROFILE 0.160

OD JACKET PROFILE 0.160 (SN 1-5, 7)

Specification: Upper 0.08  
Nominal 0  
Lower -0.08

Normal distribution: Count 1248  
Mean -0.0074  
Sigma 0.0204

6.0 sigma limits: +3.0 sigma 0.0538  
Mean -0.0074  
-3.0 sigma -0.0686

Observed beyond spec.: High 0.000 %  
Low 0.000 %  
Total 0.000 %

Estimated beyond spec.: High 0.001 %  
Low 0.019 %  
Total 0.020 %

Capability indices: CP 1.30719  
CR 0.765  
CPK 1.18627  
(upper) 1.4281  
(lower) 1.18627  
K -0.0925  
CPM 1.22711

OD JACKET PROFILE 0.160 (SN 9,10,12,14)

Specification: Upper 0.08  
Nominal 0  
Lower -0.08

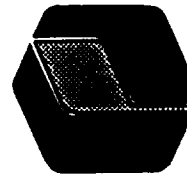
Normal distribution: Count 832  
Mean -0.0021  
Sigma 0.0265

6.0 sigma limits: +3.0 sigma 0.0774  
Mean -0.0021  
-3.0 sigma -0.0816

Observed beyond spec.: High 0.481 %  
Low 0.000 %  
Total 0.481 %

Estimated beyond spec.: High 0.097 %  
Low 0.164 %  
Total 0.262 %

Capability indices: CP 1.00629  
CR 0.99375  
CPK 0.979874  
(upper) 1.0327  
(lower) 0.979874  
K -0.02625  
CPM 1.00307



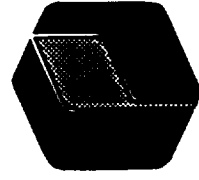
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# DIMENSIONAL SUMMARY

B/P Location	Inspection Reading	Lot #9		Lot #10		Lot #12		Lot #14	
		Range	Average	Range	Average	Range	Average	Range	Average
16.6 Dim.	12	+ .055/- .019	+ .015	+ .052/- .010	+ .017	+ .037/- .007	+ .007	+ .056/- .009	+ .018
8.85 Dim.	12	+ .049/- .037	+ .008	+ .021/- .010	+ .005	+ .051/- .003	+ .018	+ .068/+ .001	+ .025
21.50 Dia.	12	+ .003/- .011	- .002	- .005/- .020	- .010	+ .014/- .006	+ .002	+ .006/- .007	- .001
26.37 Dia.	12	+ .022/- .030	- .000	+ .011/- .010	+ .001	+ .026/- .001	+ .013	+ .017/- .004	+ .006
23.89 Dia.	12	+ .026/- .028	+ .002	+ .020/- .012	+ .004	+ .075/+ .008	+ .034	+ .058/- .040	+ .013
.160 ABC	208	+ .046/- .040	- .002	+ .103/- .074	- .003	+ .088/- .053	+ .001	+ .048/- .043	- .006

Dimensions reported as deviations from nominal



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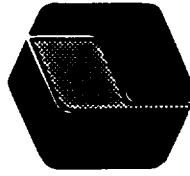
# **METALLURGICAL RESULTS OF GATING DOE**

**Lots 9 - 14**

---

**JIM HOWCROFT**

- DOE results clearly define best combination of TGC and gating.
- Quality of parts resulting from Gating DOE will meet NASA ultimate requirements.



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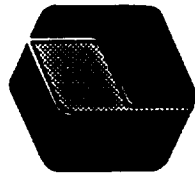
# DESIGN OF EXPERIMENT GATING

---

TREATMENT:	LEVEL OF TREATMENT:
------------	---------------------

• Direction of TGC*	A	Standard	Reverse
• Size of Aft Gate	B	Large	Small
• Size of Jacket Gate	C	Round	Square
• Level of TGC	D	High	Low
• Style of Aft Gate	E	Ring	Spoke

\*Thermal Gradient Control

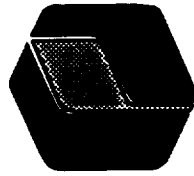
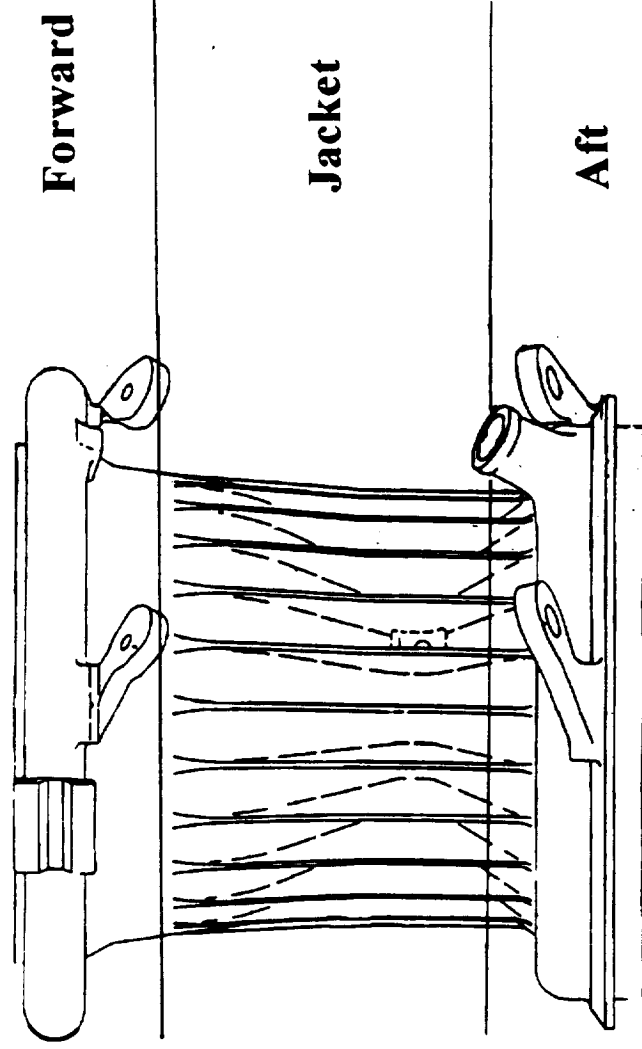


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# DESIGN OF EXPERIMENT GATING

---

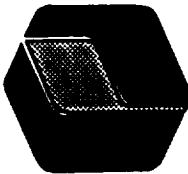
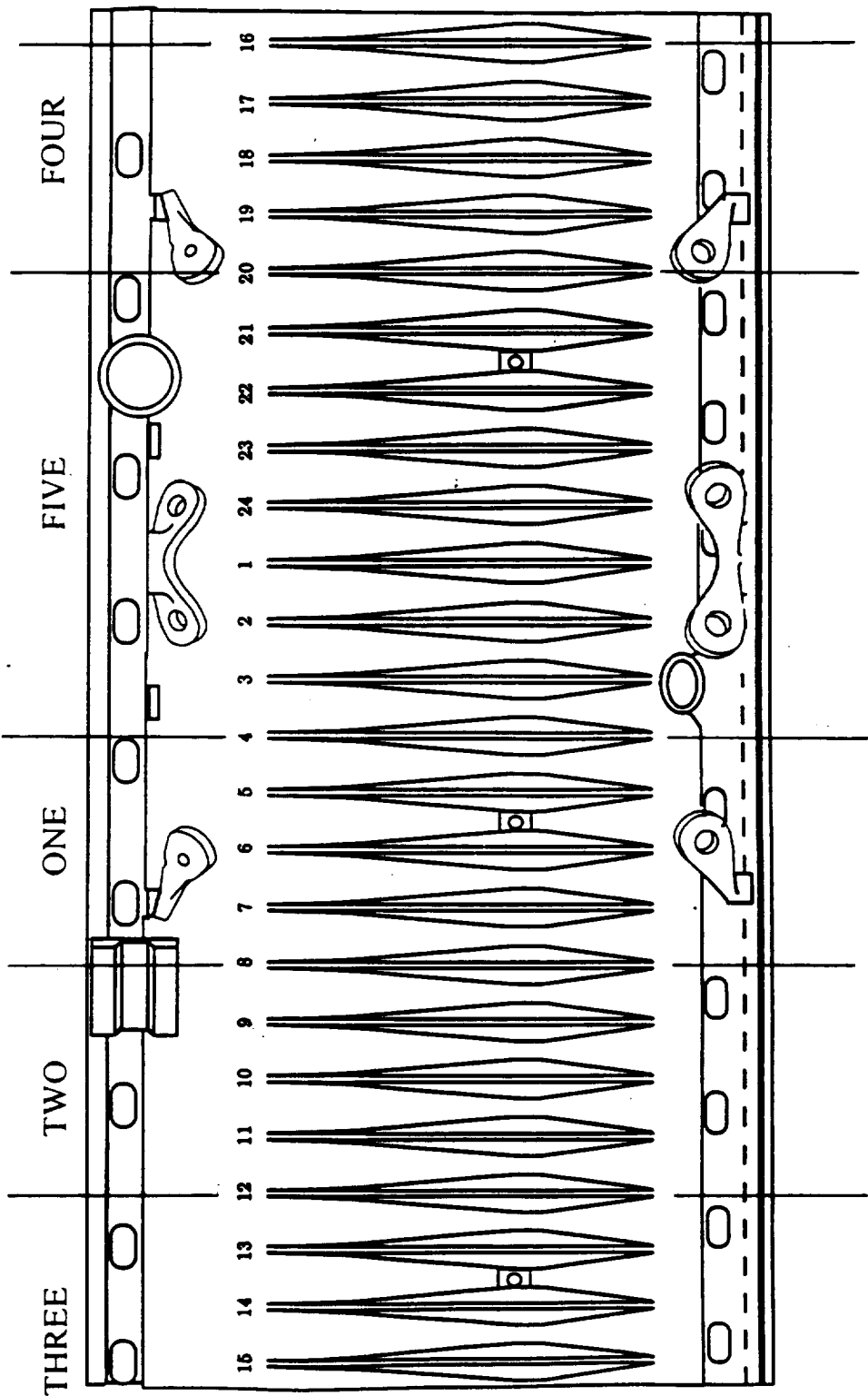


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# DESIGN OF EXPERIMENT GATING

DOE SECTION  
MAP 20013

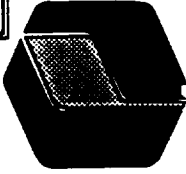


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# DESIGN OF EXPERIMENT GATING

DESIGN EASE	A	B	C	D	E
	DIRECTION TGC	SIZE AFT GATE	SIZE JACKET GATE	LEVEL TGC	STYLE AFT GATE
Lot No. 009 Section 1	Std.	Small	Square	High	Spoke
Section 2	Std.	Large	Round	High	Spoke
Section 3	Rev.	Small	Round	High	Spoke
Section 4	Rev.	Large	Square	High	Spoke
Lot No. 010 Section 1	Rev.	Large	Round	Low	Spoke
Section 2	Std.	Large	Square	Low	Spoke
Section 3	Rev.	Small	Square	Low	Spoke
Section 4	Std.	Small	Round	Low	Spoke
Lot No. 012 Section 1	Rev.	Large	Square	Low	Ring
Section 2	Std.	Large	Round	Low	Ring
Section 3	Rev.	Small	Round	Low	Ring
Section 4	Std.	Small	Square	Low	Ring
Lot No. 014 Section 1	Rev.	Large	Round	High	Ring
Section 2	Std.	Large	Square	High	Ring
Section 3	Rev.	Small	Square	High	Ring
Section 4	Std.	Small	Round	High	Ring



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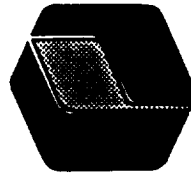
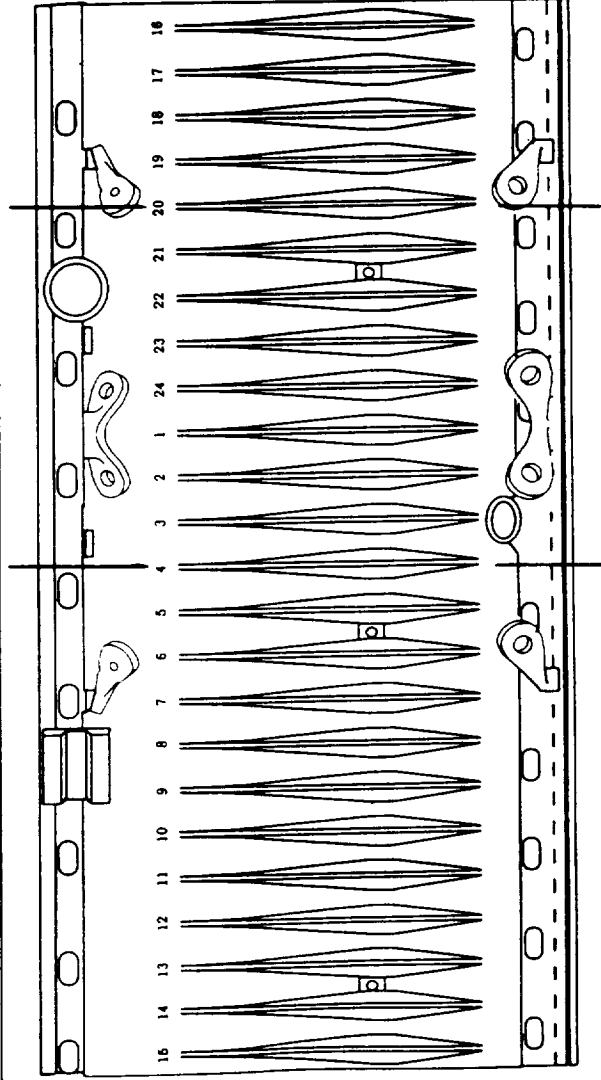


# DESIGN OF EXPERIMENT GATING

## SECTION 5

DESIGN EASE

	A	B	C	D	E
	Direction of TGC	Size Aft Gate	Size Jacket Gate	Level TGC	Style Aft Gate
Lot No. 009	Std	Unique to section	Web 21-22 square Web 1-2 round	High	Spoke
Lot No. 010	Std	Unique to section	Web 21-22 square Web 1-2 round	Low	Spoke
Lot No. 012	Std	Unique to section	Web 21-22 square Web 1-2 round	Low	Ring
Lot No. 014	Std	Unique to section	Web 21-22 square Web 1-2 round	High	Ring



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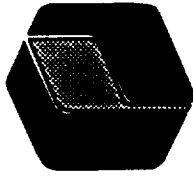
NASA

# P/N 20013 DOE DATA SHEET

Lot No. \_\_\_\_\_  
 Zone \_\_\_\_\_  
 Inspection \_\_\_\_\_

DOE SECTION	LOCATION	LENGTH	WIDTH	SEVERITY

LENGTH x WIDTH x SEVERITY = SCORE



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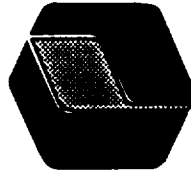
# DESIGN OF EXPERIMENT GATING

---

## SUMMARY

<u>TREATMENT</u>	<u>CHOICE</u>
• Direction of TGC	• Standard
• Size of Aft Gate	• Large
• Size of Jacket Gate	• Round*
• Level of TGC	• Fwd Manifold - Low • Jacket - Low • Aft Manifold - High
• Style of Aft Gate	• Ring

\* Jacket Gate change may be included in process DOE.



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**P/N 20013**

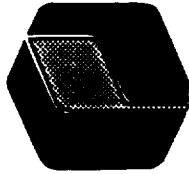
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**HOT FIRE**

**Lot No. 015**

**Lot No. 016**

- |   |   |                         |   |                         |
|---|---|-------------------------|---|-------------------------|
| • | Spoke Gate - Same as Lots 004-007               | •                       | Ring Gate - Small                           |                         |
| • | Jacket Gate - Round                             | •                       | Jacket Gate - Round                         |                         |
| • | TGC- Forward Manifold<br>Jacket<br>Aft Manifold | - Low<br>- Low<br>- Low | TGC- Fwd Manifold<br>Jacket<br>Aft Manifold | - Low<br>- Low<br>- Low |



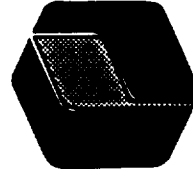
**Precision Castparts Corp.**



# MANUFACTURING SEQUENCE

Lot 015, 016

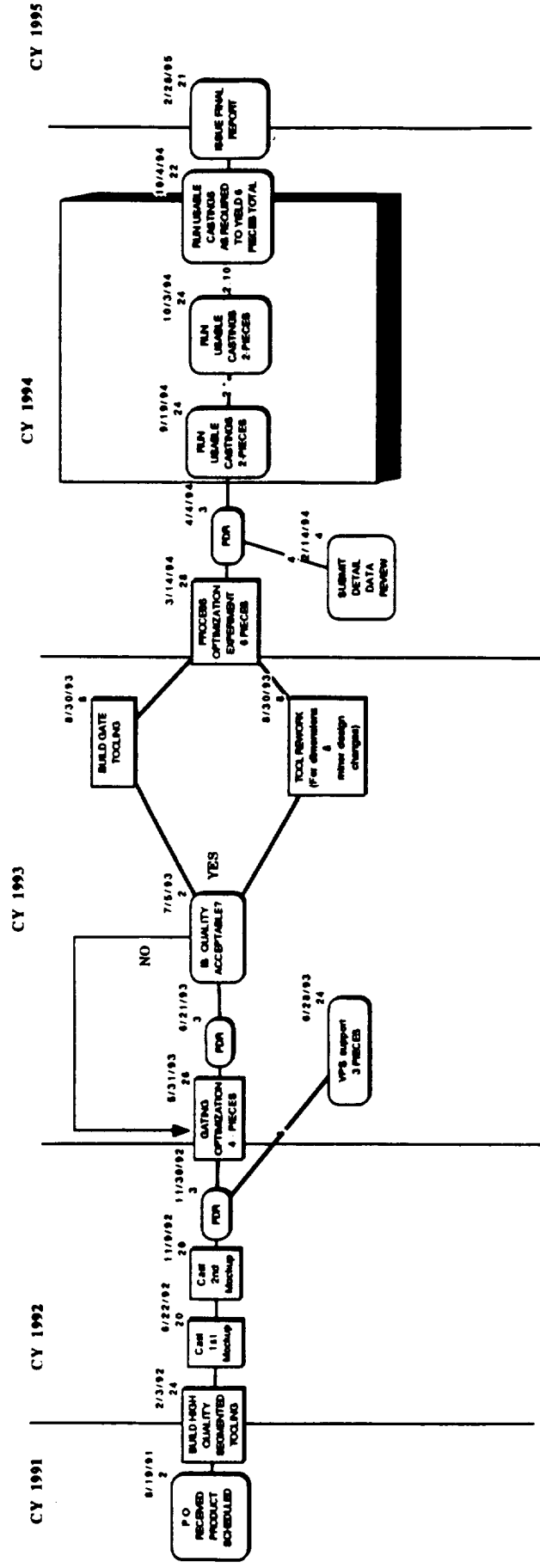
AFTER CAST	WINDOW WELD
• Belt grind gates/drains	• Two patch - Forward Manifold
• Sandblast	• Two patch - Aft Manifold
• Thermal etch	• FPI inspect patches
• Cap weld gates	• Visual dimensional patches
• Visual inspect	• X-ray patches
• Weld if required	• Proceed when accepted to next window closure sequence
• FPI	• After all patches installed, inspected and accepted, HIP
• Repair	
• HIP	
• Finish grind gates	
• Blend welds	
• FPI	
• Repair	
• X-ray - full	
• Repair	
• Begin window closure sequence	



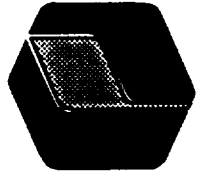
Precision Castparts Corp.

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# DEVELOPMENT PROCESS



- ENGINEERING SAMPLES
- GATING OPTIMIZATION DOE
- PROCESS SENSITIVITY DOE
- PROTOTYPE PARTS = PROCESS DEMONSTRATION
- ADDITIONAL "BEST EFFORT" CASTING



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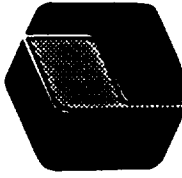
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**LOTS 9 - 14**  
**NON-DESTRUCTIVE TESTING**

---

**BRUCE HAPHEY**

- **APPLICATION OF BASIC INSPECTION METHODS**
- **PROBLEM AREAS ADDRESSED**
- **KNOWLEDGE GAINED**



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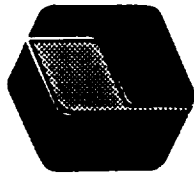
# **PART QUALITY**

**Lots 9 - 14**

---

**Applications of basic inspection methods:**

- **X-Ray**
- **Penetrant**
- **Visual**
- **Dimensional**



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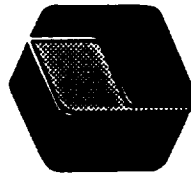
# **NON-DESTRUCTIVE TESTING**

**Lots 9- 14**

---

## **Problem areas addressed:**

- **Inspection fixturing**
  - **X-Ray**
  - **Penetrant**
- **Manifold inspection**
  - **X-Ray**
  - **Penetrant**
  - **Visual**
  - **Dimensional**
- **Welding**
  - **Distortion**
  - **Mis-match**
  - **Drop through**



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# **NON-DESTRUCTIVE TESTING**

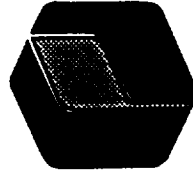
**Lots 9 - 14**

---

## **Knowledge gained:**

- **Inspection methods**

- **X-Ray**
- **Penetrant**
- **Visual**
- **Dimensional**
- **Welding**



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## **CASTING HARDWARE ACCEPTANCE TEST & INSPECTION PLAN**

The primary goal of Precision Castparts Corp's casting inspection plan for the NASA Advanced Main Combustion Chamber (AMCC) has been to evaluate, develop and finalize the inspection methods and processes earlier identified in DR-02 as primary casting evaluation technology.

The non-destructive inspection methods of X-ray, Penetrant and Visual/Dimensional, earlier identified as necessary to accomplish this goal, are consistent with the present capabilities of Precision Castparts Corp.

All non-destructive testing inspection difficulties have been satisfactorily resolved with the exception of the inspection of the manifolds on the forward and aft end of the main combustion chamber throat.

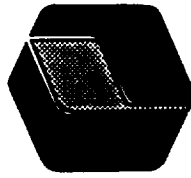
From the standpoint of inspection technique development, some welding process considerations and attendant inspection problems related to complex casting configuration required careful attention to potentially critical manufacturing problems associated with NDT inspectability and casting processing.

The principle inspection difficulty arises from the limited access available though the manifold "windows". These "windows" require a great deal of expertise in proper X-ray film placement within the manifold interior.

Inspectability for penetrant, visual and dimensional inspection are equally difficult.

The "windows" are multiple access "ports" provided in each manifold and are required for casting construction.

Each "window" is deliberately kept to the smallest size practical yet large enough to provide the



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The NASA logo, consisting of the word "NASA" in a bold, sans-serif font, with a stylized "N" and "A".

necessary inspection access to the internal surface area of the manifold.

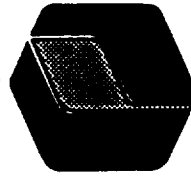
The presence of the "windows" in the finished manifolds are unacceptable to the function of the manifolds; consequently, subsequent closure by welding a patch of the same alloy, shape and thickness as the manifold section is required.

As part of the inspection process, each individual "window" weld requires post-weld visual, dimensional, penetrant and X-ray inspection, to confirm acceptability, prior to welding the next adjacent "window" patch. Consequently, the casting manifold section receives a number of X-ray, penetrant, visual and dimensional inspections.

The X-ray, penetrant, and dimensional inspection techniques presently utilized on the preliminary development castings have matured during the casting development process such that a final X-ray technique has been developed that represents a complete and final product consisting of specific views and exposure parameters necessary to produce high sensitivity levels reliably and consistent with standard industry practices.

Penetrant inspection procedures and processes have matured equally as well such that penetrant inspection of the manifolds, although difficult, can be accomplished with a degree of confidence that reliable results can be consistently achieved.

PCC has established, for the generic inspection of this casting, that the application of a high sensitivity water-washable fluorescent dye penetrant is best suited for detection of the type of surface discontinuities particular to castings of this size and complexity. Considerations were given to the casting surface condition,



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material, processing characteristics, casting process compatibility and the ability to detect the desired discontinuity types and levels expected in a casting of this type.

The water-washable type of penetrant is particularly suited to the surface condition of castings as produced by the investment casting process. Casting surface finishes are fairly rough, on the order of about 60 rms, and as a consequence require penetrants that exhibit removal characteristics that are attuned to the casting surface condition, the type of casting material, the size and type of discontinuities to be detected, and the processing procedures.

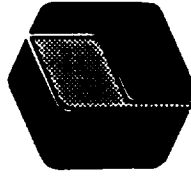
The penetrant selected has the physical properties required to consistently produce the penetrant sensitivity necessary to consistently detect the discontinuity level desired.

PCC has specified Magnaflux penetrant type ZL-67 as the desired penetrant most closely fitting the necessary requirements.

Special Penetrant Inspection techniques require the incorporation of a blacklight boroscope for pre- and post-weld "window" closure inspection of the manifolds as well as final penetrant inspection of the fully closed manifolds after final heat treat.

Equally matured are the Visual/Dimensional Inspection techniques and equipment necessary to properly validate internal manifold dimensions and visual condition.

Visual inspection is expanded with the incorporation of a boroscopic inspection requirement to cover the internal passages of the casting.



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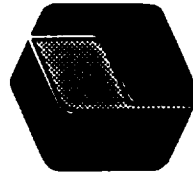
NASA

Applied principally during the preliminary inspection cycles of "window" closure, this boroscopic inspection operation is necessary to conclude a detailed examination of the inner surface of the AMCC manifolds and to evaluate the interior condition of the welds made in closing the manifold's "windows".

It is necessary, for dimensional evaluation of the manifold interior, to dimensionally confirm that welds in the manifold's interior can be evaluated for mis-match, drop-through or potential over-benching of the interior wall.

The metrology tools, techniques and training required to perform this important task have been developed successfully with confidence in the accuracy of measurement.

To summarize, the major problems in the inspection of the AMCC have been identified and resolved to the extent that a difficult inspection regime can be accomplished reliably and accurately.



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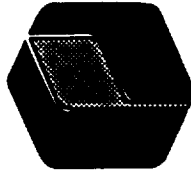
# **PROCESS DOE**

**WHAT IS OUR STRATEGY - Lots 17 - 20**

---

**BRUCE MILLER**

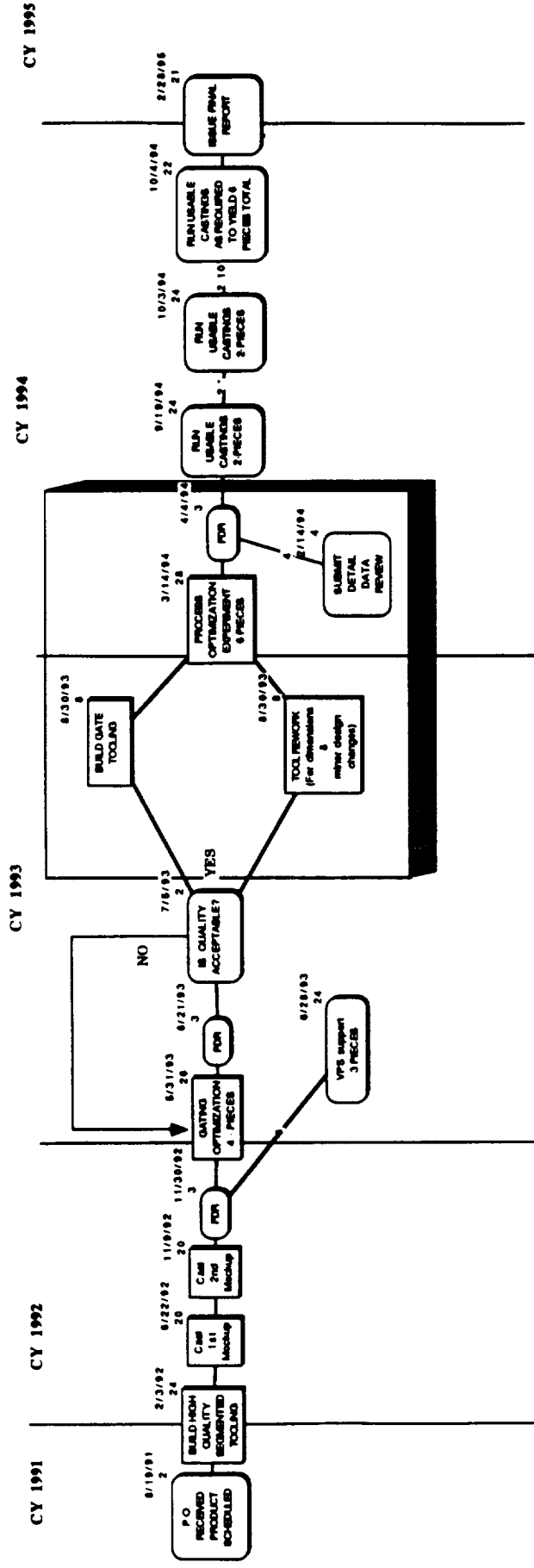
- **NAIL DOWN METAL TEMPERATURES**
- **REFINE TGC APPLICATION**
- **FIND OUT HOW ROBUST OUR PROCESS IS**



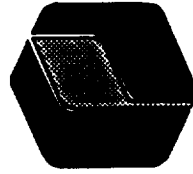
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# DEVELOPMENT PROCESS



- ENGINEERING SAMPLES
- GATING OPTIMIZATION DOE
- **PROCESS SENSITIVITY DOE**
- PROTOTYPE PARTS = PROCESS DEMONSTRATION
- ADDITIONAL "BEST EFFORT" CASTING



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## **CORE GROUP - PROCESS DOE**

---

### **TEAM MEMBER**

**Bruce Miller - Part Engineer**

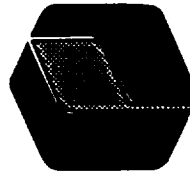
### **CONSULTANTS**

**Nick Vlessis - Part Engineer**

**Jim Howcroft - Part Engineer**

**Jeff Miller - Part Engineer**

**Nancy Dean - Metallurgical Engineer**



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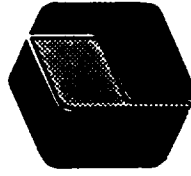
# **DESIGN OF EXPERIMENT PROCESS**

---

## **CONSIDERATIONS:**

- **Mold temperature**
- **Metal temperature**
- **Shell thickness**
- **Shell system in Forward and Aft Manifolds**
- **Shell insulation/removal**
- **Level of TGC\***
- **Shape/size of TGC**
- **Timing of TGC**

**\*Thermal Gradient Control**



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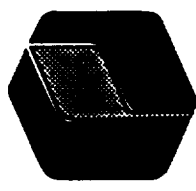
**NASA**

# DESIGN OF EXPERIMENT PROCESS

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## TREATMENT:

- Metal temperature whole part
- Shell system - Manifold whole part
- Shape of TGC within part
- Timing of TGC within part

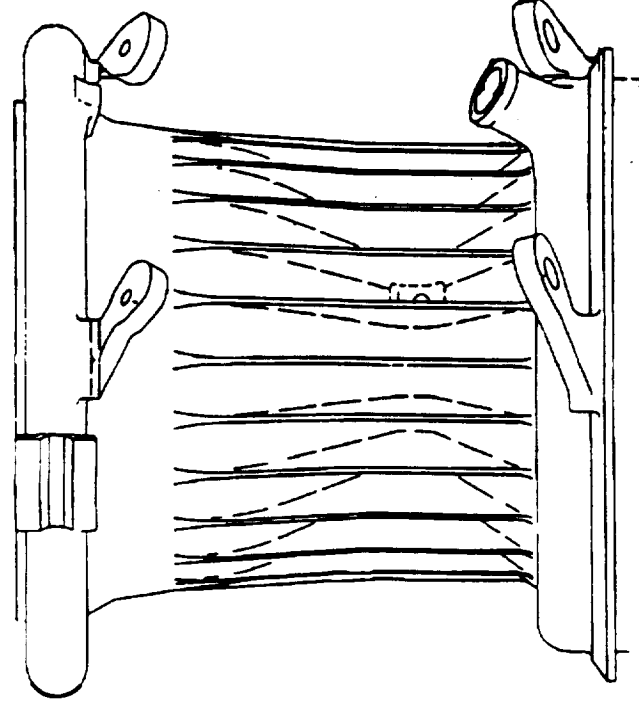


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# DESIGN OF EXPERIMENT PROCESS

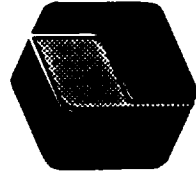
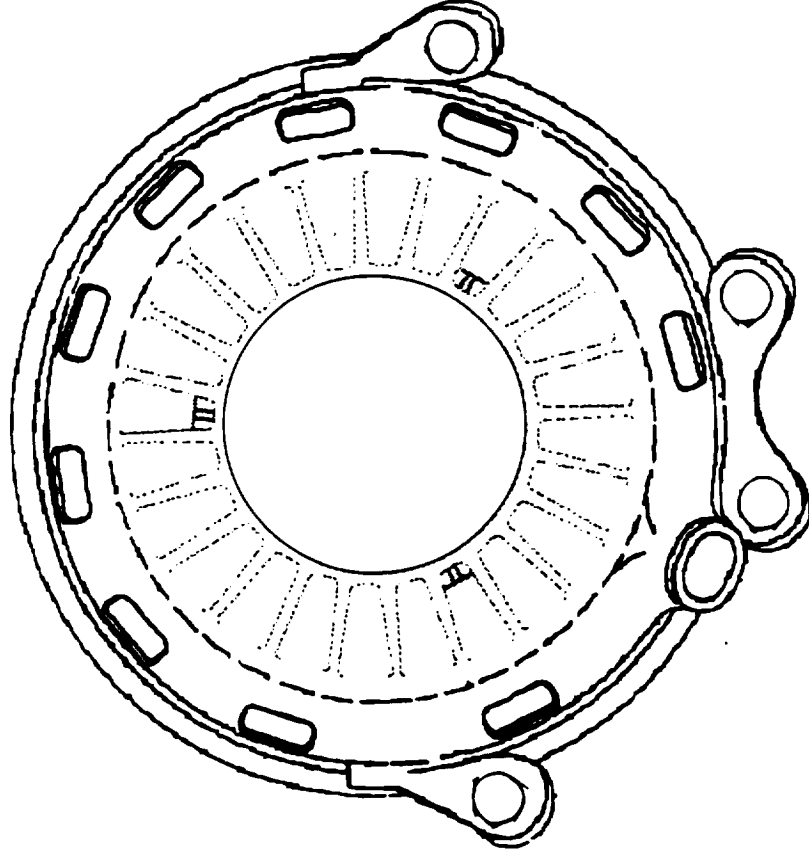
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Forward  
Manifold

Jacket

Aft  
Manifold



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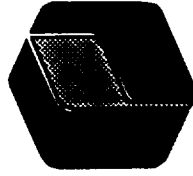
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# **PROCESS DOE DIMENSIONAL EVALUATION OF LOTS 17-20**

---

**PAM WRIGHT**

- **WHAT WE ARE LOOKING FOR IN THIS  
PROCESS**



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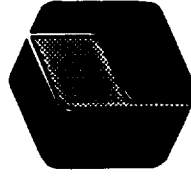
**NASA**

# **HOT FIRE PARTS LOTS 015 AND 016**

- HAND FAB USING NEW BLUEPRINT DIMENSIONS

# **PROCESS DOE LOTS 017 THRU 020**

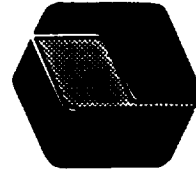
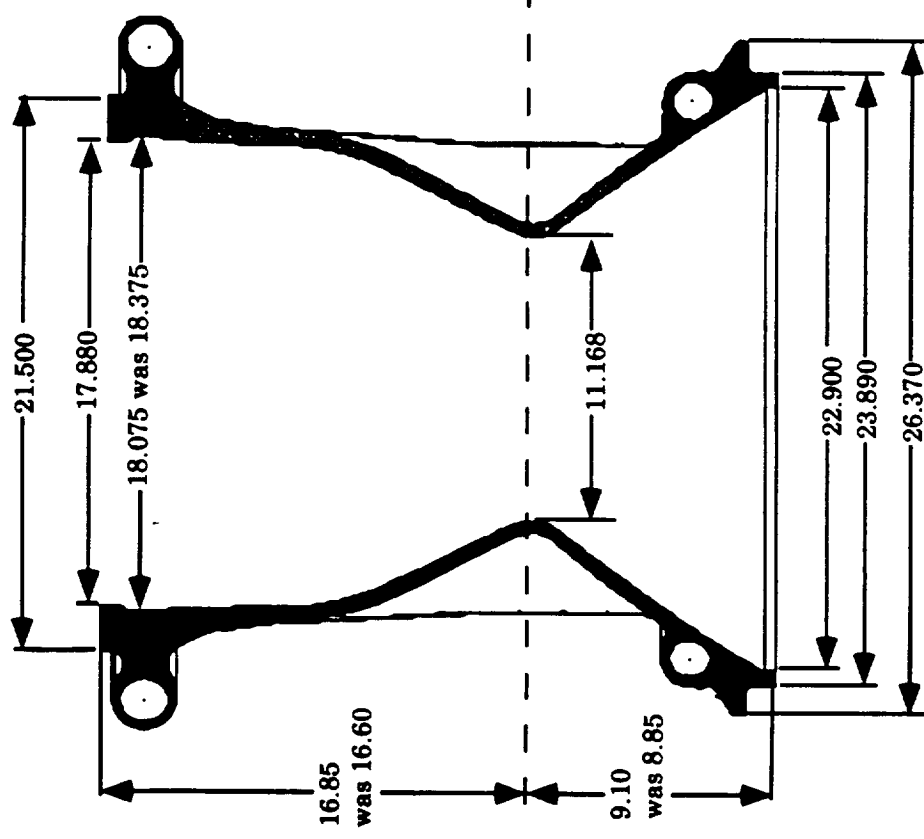
- TOOL REWORKED



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# NASA AMCC BLUEPRINT DIMENSIONS



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Technical drawing of a mechanical part, likely a bracket or support arm, showing two views: a front view (top) and a side view (bottom).

**Front View (Top):**

- Left vertical dimension: Build up .250"
- Left horizontal dimension: B/u .150" tapered to 0"
- Right horizontal dimension: B/u .070" tapered to 0"
- Right vertical dimension: Build up .250"

**Side View (Bottom):**

- Left horizontal dimension: B/u .070" tapered to 0"
- Right horizontal dimension: B/u .070" tapered to 0"
- Right vertical dimension: Build up .250"

The drawing includes various geometric features such as fillets, chamfers, and circular holes, all defined by precise dimension lines and leader arrows.

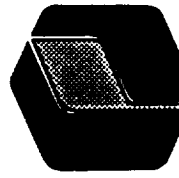


# VSN



# **DIMENSIONAL INSPECTION**

- WAX COMPONENT - CONTROLLED DIMENSIONS
- ASSEMBLED WAX - CMM  
CONTROLLED DIMENSIONS
- METAL CASTING - CMM  
CONTROLLED DIMENSIONS



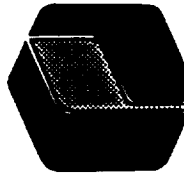
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## SUMMARY OF P/N 20013

---

Lot 001	- Cut up	- Engineering Evaluation
002	- Ship	- Partially completed. Limited NDT work.
		No window closure
003	- Cut up	- Engineering Evaluation
004	- Ship	- First full process casting
005	- Ship	
006	- Cut up	- Engineering Evaluation
007	- Ship	
008	- Cancel	
009	- Gating DOE	
010	- Gating DOE	
011	- Scrap at Investing	
012	- Gating DOE	
013	- Scrap at Investing	
014	- Gating DOE	
015	- Scheduled to ship Oct. 1993	
016	- Scheduled to ship Oct. 1993	



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**PRELIMINARY DESIGN REVIEW**  
**AMCC CASTING DEVELOPMENT**

**SEPTEMBER 21, 1994**

# **PRECISION CASTPARTS CORP.**

**Presentation to**

**NASA**

**September 21, 1994**

## **Introductions:**

### **PCC AMCC Development Team**

**Pam Wright, Dimensional Engineer**

**Joe Franich, Quality Engineer**

**Steve Clement, Part Engineer**

**Rick Soll, Product Engineer**

**Steve Irvine, Program Manager**

**Penny Tibedo, Account Manager**

**Pat Maloney, Technician**

# **PRELIMINARY DESIGN REVIEW AGENDA**

## **AMCC CASTING DEVELOPMENT**

**Wednesday, September 21, 1994**

<b>Introduction</b>	<b>Steve Irvine</b>	<b>9:00 – 9:15</b>
<b>Part &amp; Gating Review</b>	<b>Steve Clement</b>	<b>9:15 – 10:00</b>
<b>Break</b>		<b>10:00 – 10:15</b>
<b>Process DOE</b>	<b>Steve Clement</b>	<b>10:15 – 11:30</b>
<b>Lots 17, 20, 21, 22</b>		
<b>Lunch</b>		<b>11:30 – 12:30</b>
<b>Dimensional Review</b>	<b>Pam Wright</b>	<b>12:30 – 2:00</b>
<b>Break</b>		<b>2:00 – 2:15</b>
<b>Inspection Identification &amp; Rejection Criteria</b>	<b>Steve Clement/ Pam Wright</b>	<b>2:15 – 3:15</b>
<b>Summary/Open Discussion</b>	<b>Steve Irvine</b>	<b>3:15</b>



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# PROGRAM OBJECTIVE

---

Produce a Structural Jacket and Coolant Manifold casting design that is:

- More reliable
- More predictable
- More cost effective

than the wrought, machined and heavily welded design used for the current SSME Main Combustion Chamber (MCC).



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**SUMMARY – AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**PART & GATING REVIEW**

---

- History
- Gating used on Lots 015 & 016
- Gating used for Process DOE



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# SUMMARY – AMCC Large Throat Castings

## NASA Dwg. #96M66441 / PCC P/N 20013

LOT #	DESCRIPTION	COMMENTS	PDR Rvw.
001	Cut-up	Engineering Evaluation	12/26/92
002	Shipped 3/92	Partially Processed – No window closure	
003	Cut-up	Engineering Evaluation	
004	Shipped 9/92	Fully Processed – Limited NDTE Req' mnts	10/12/93
005	Shipped 11/92	Fully Processed – Limited NDTE Req' mnts	
006	Cut-up	Engineering Evaluation	
007	Shipped 12/92	Fully Processed – Limited NDTE Req' mnts	
008	Cancel	—	
009	Gating DOE	Engineering Evaluation	
010	Gating DOE	Engineering Evaluation	
011	Scrap	Broken Mold in Investing	



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# SUMMARY – AMCC Large Throat Castings

## NASA Dwg. #96M66441 / PCC P/N 20013

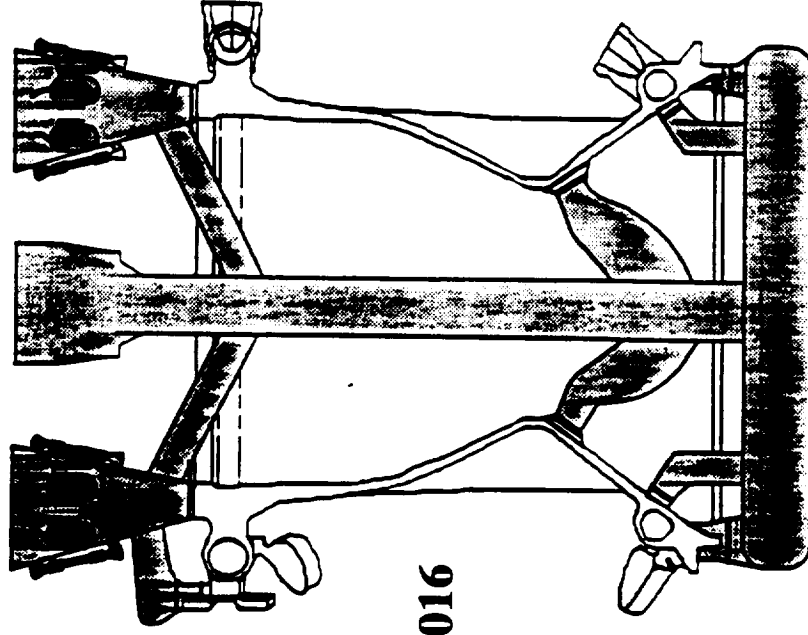
LOT #	DESCRIPTION	COMMENTS	PDR Rvw.
012	Gating DOE	Engineering Evaluation	10/12/93
013	Scrap	Broken Mold in Investing	
014	Gating DOE	Engineering Evaluation	
015	Shipped 10/93	Fully Processed	9/21/94
016	Shipped 10/93	Fully Processed	
017	Process DOE	Engineering Evaluation	
018	Scrap	Mis-pour in Foundry / Height Limitation	
019	Scrap	De-wax Cracks in Investing	
020	Process DOE	Engineering Evaluation	
021	Process DOE	Engineering Evaluation	
022	Process DOE	Engineering Evaluation	



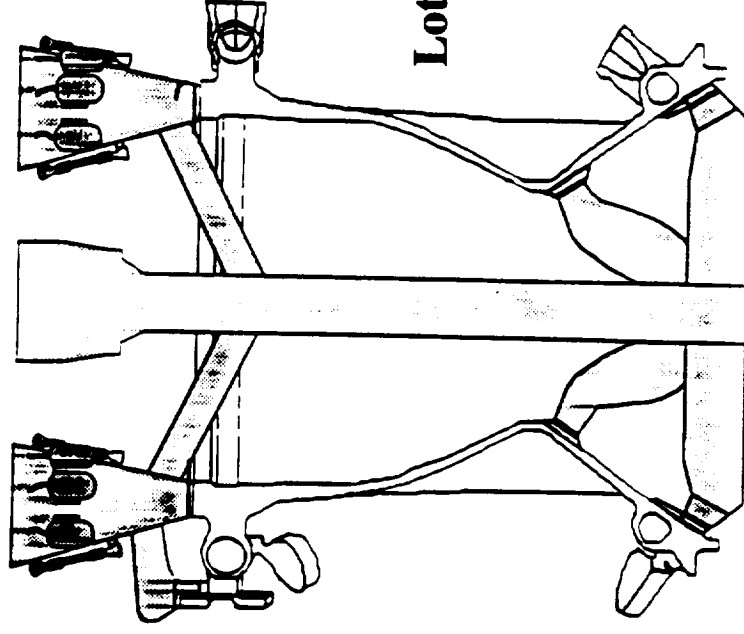
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**AMCC Large Throat Castings**  
**NASA Dwg. #96M66441 / PCC P/N 20013**  
**Gating Variations**

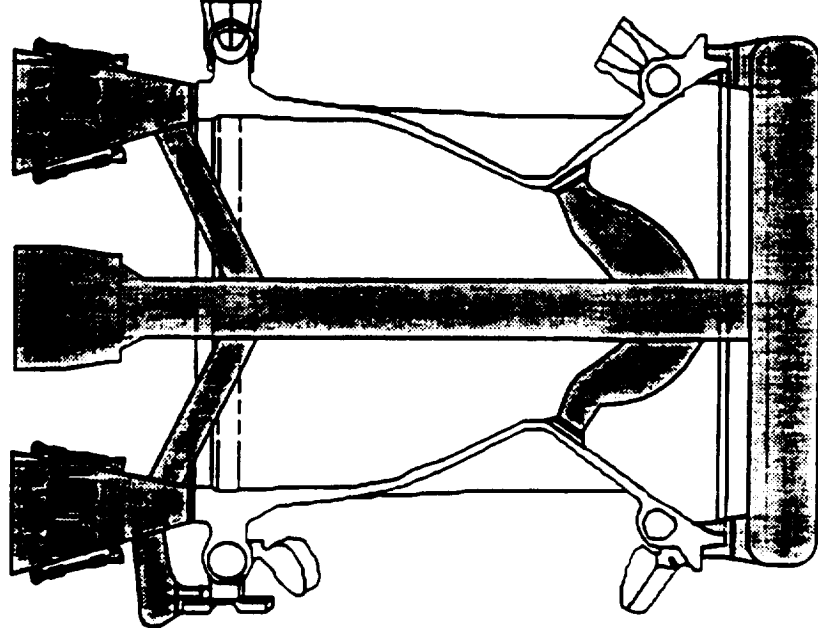


**Lot 016**



**Lot 015**

**AMCC Large Throat Castings**  
**NASA Dwg. #96M66441 / PCC P/N 20013**  
**Gating on Process DOE Lots 017, 020, 021 & 022**



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**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**PROCESS DOE Lots 17, 20, 21, & 22**

---

- Results
  - Overall Quality
  - Process Variables
  - Effect of shape and location of TGC
  - Effect of metal temperature
  - Effect of time delay of TGC
  - Lab results
- Summary



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**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

- Overall quality is very good
- Destructive Chem mill was required to evaluate impact of process DOE variables \*

\* ( Except for shape and location of TGC )



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**AMCC Large Throat Castings**  
**NASA Dwg. #96M66441 / PCC P/N 20013**

**Process DOE Variables**

- Shape & Location of TGC      Within Part
- Metal Temperature      Whole Part
- Time Delay of Aft  
Manifold TGC\*      Whole Part
- Time Delay of Jacket TGC      Within Part

\* Thermal Gradient Control



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# AMCC Large Throat Castings NASA Dwg. #96M66441 / PCC P/N 20013

## DOE Response Variables

( Post chem mill FPI results)

Variable	Standard Pour Temp.		Lowered Pour Temp.	
	Early TGC	Late TGC	Early TGC	Late TGC
Lot #	020	022	017	021
# Shrink Indications	42	40	34	11
Total Area of Shrinkage	27.42"	36.09"	33.54"	9.71"
Grade (Class X Area)	151.75	188.98	186.49	58.92

**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

## **– Effect of Shape & Location of TGC**

**( System #1 vs. System #2 )**

- . TGC System # 1 is Clear Winner**
- . Improvement is Statistically Significant**

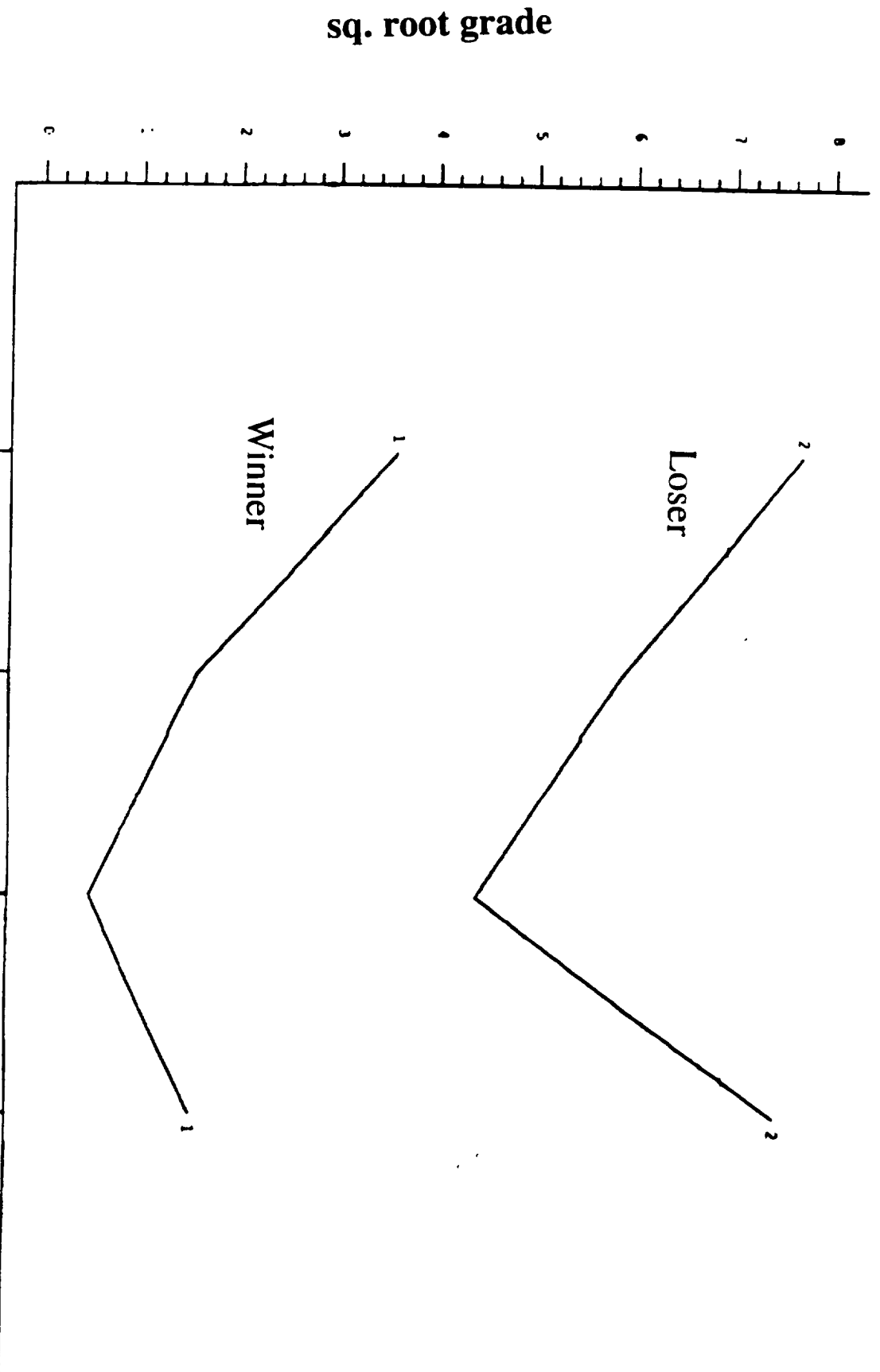


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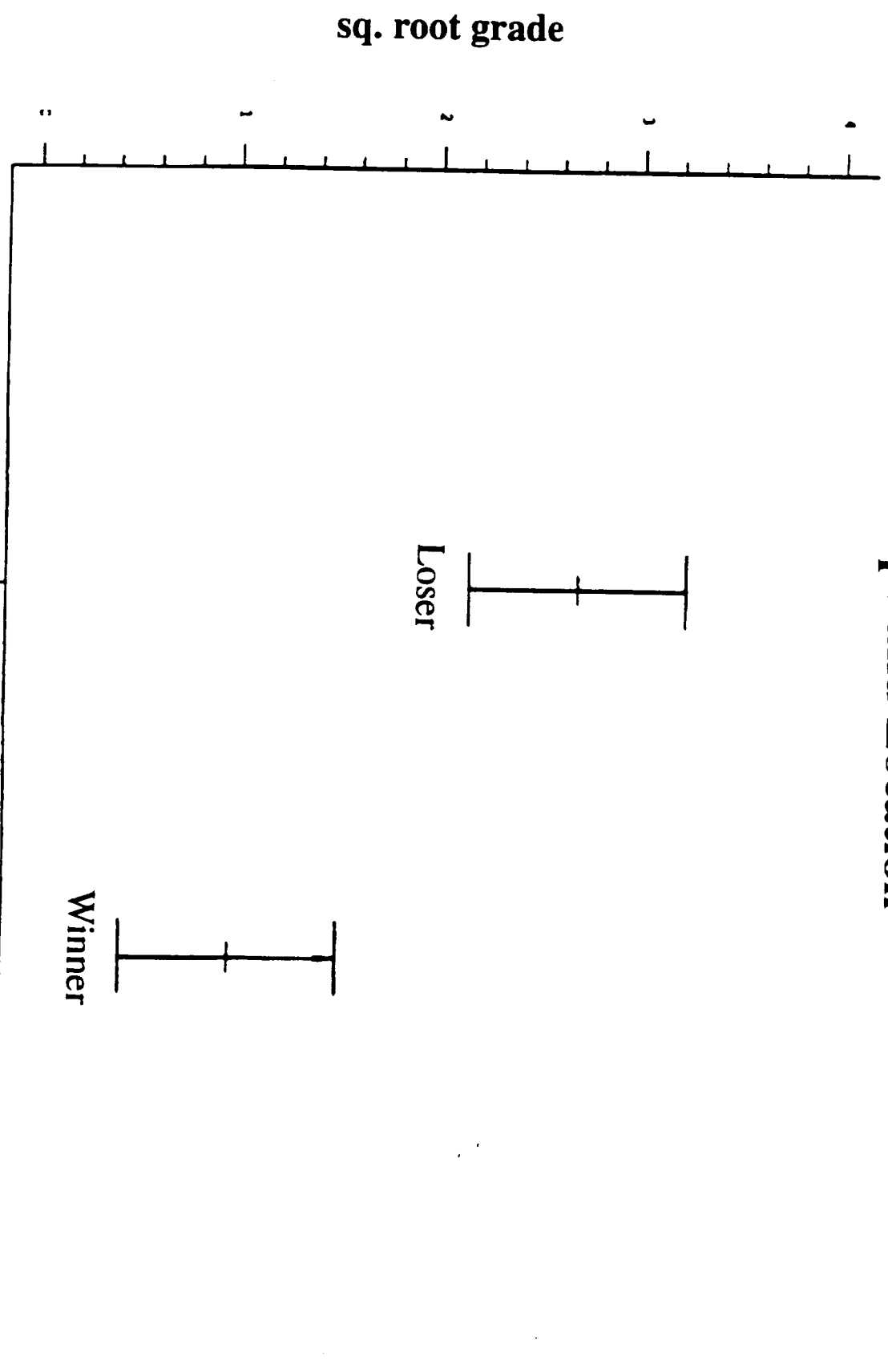




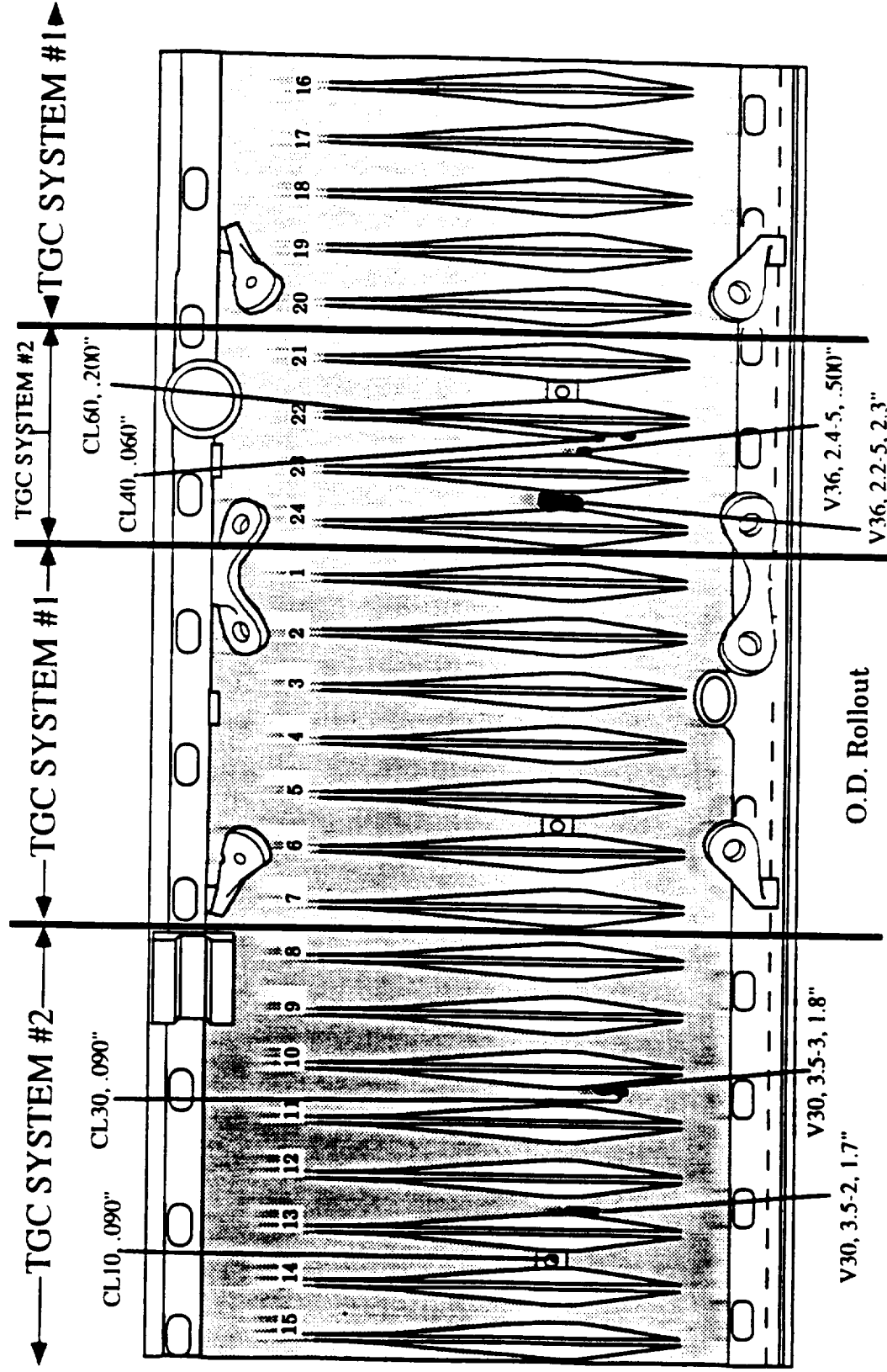
# Effect of TGC Shape and Location



# Statistical Significance of TGC Shape and Location



# Effect of TGC\* Shape & Location (PCC P/N 20013)



( Lot 017 Pre-HIP Results )

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**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

## **– Effect of Metal Temperature**

- DOE Points Toward Lower  
Pour Temp**



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**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

## **– Effect of Time Delay of Aft Manifold TGC**

- Late TGC is Apparent Winner**



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NASA Dwg. #96M66441 / PCC P/N 20013**

## **– Effect of Time Delay of Jacket TGC**

- No Apparent Winner**



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**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**– LAB RESULTS: Microshrink**

- 9.6% & 6.3% shrink indications in section C1–2 of Lot 017  
were caused by a gating variable at the inlet nozzle**
- 4.5% shrink indication in section C5–1 of Lot 020 is  
the worst indication without an attributable cause**



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**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**– LAB RESULTS: Void**

- .100” long, with .060” depth, void in section A5–1J in Lot 022**
- Lab analysis cannot accurately determine the root cause of the indication. Most probable cause is a large ceramic inclusion.**
- Process DOE parts did not have a casting filter due to a height limitation at casting.**
- The next parts will have drop-in filters.**



**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**– GRAIN SIZE**

- Maximum Columnar Grain: 1.3”**
- Maximum Equiaxed Grain: 0.9”**



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## GRAIN SIZE EVALUATION

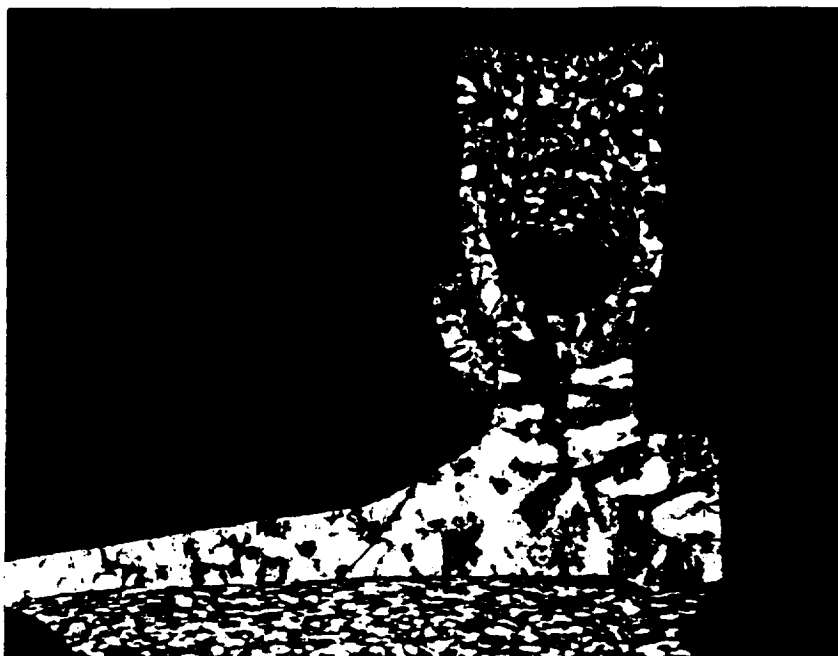


Figure 3

SEGMENT A-5

End view



Figure 4

SEGMENT A-5

Maximum equiaxed grain size: 0.4"

Maximum columnar grain size: 1.3"

Mag 1X

**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**– LAB ANALYSIS : IGA / IGO**

**– Maximum Observed IGA / IGO is .001”**



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**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**– LAB RESULTS: Eta Phase**

- Local areas of Eta phase at grain boundaries in heavy sections**



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## ETA PHASE EVALUATION



Figure 33

SECTION A1-2F

ETA PHASE

Etched: 10% Oxalic Acid, electrolytic

Mag 50X

Mount Number P 11141



Figure 34

SECTION A1-2F

ETA PHASE

Etched: 10% Oxalic Acid, electrolytic

Mag 200X

Mount Number P 11141

**AMCC Large Throat Castings  
NASA Dwg. #96M66441 / PCC P/N 20013**

**SUMMARY**

- Overall Part Quality is Very Good
- Process DOE selects TGC system #1
- Process DOE points toward a lower pour temperature
- Process DOE sets the aft manifold TGC time delay



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# **DIMENSIONAL REVIEW**

## **Lots 17, 20, 21, & 22**

---

**Pam Wright**

- Process DOE variations did not influence Dimensional integrity of the part.
- Casting is dimensionally stable.

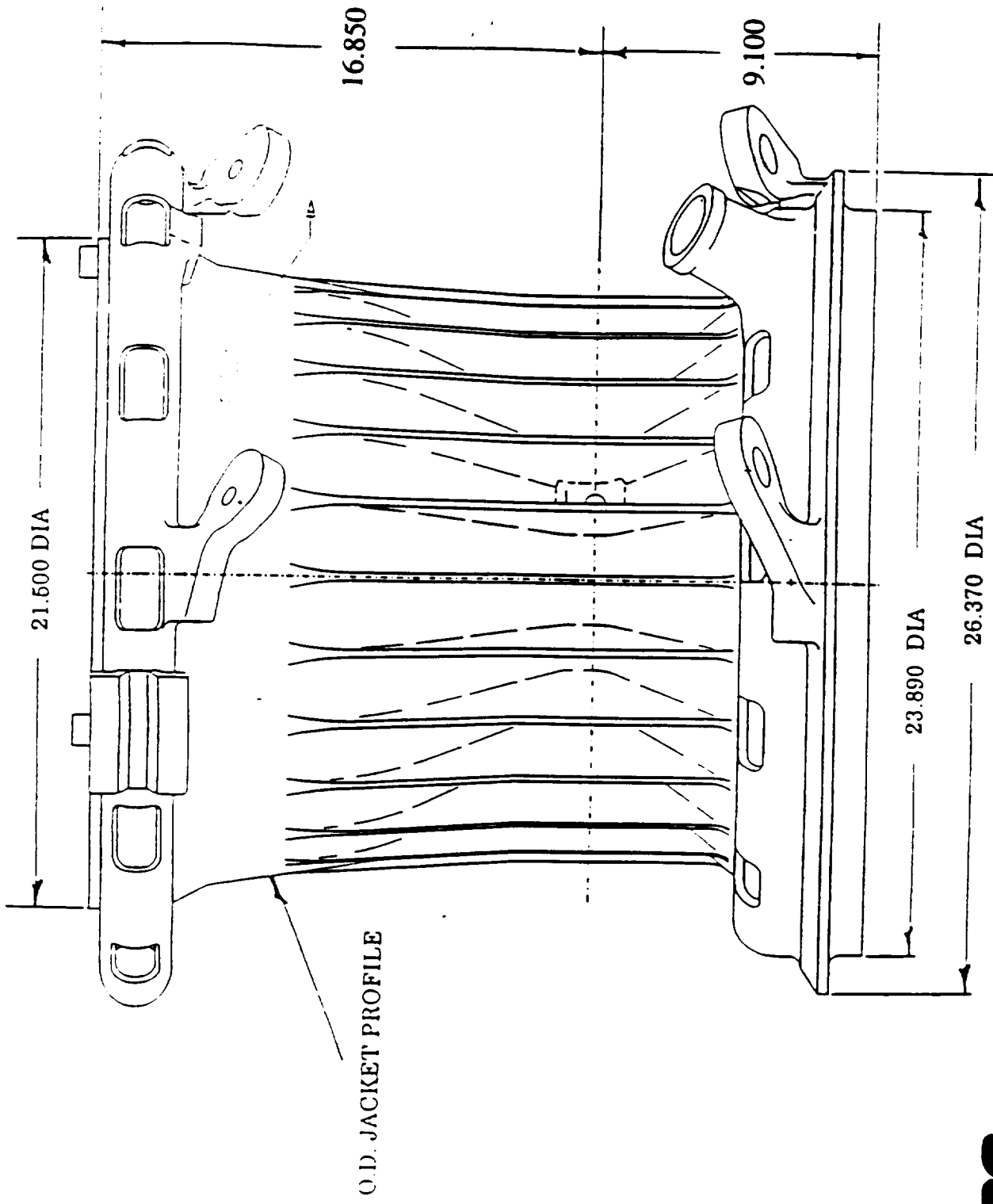
C-4



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# NASA AMCC BLUEPRINT DIMENSIONS



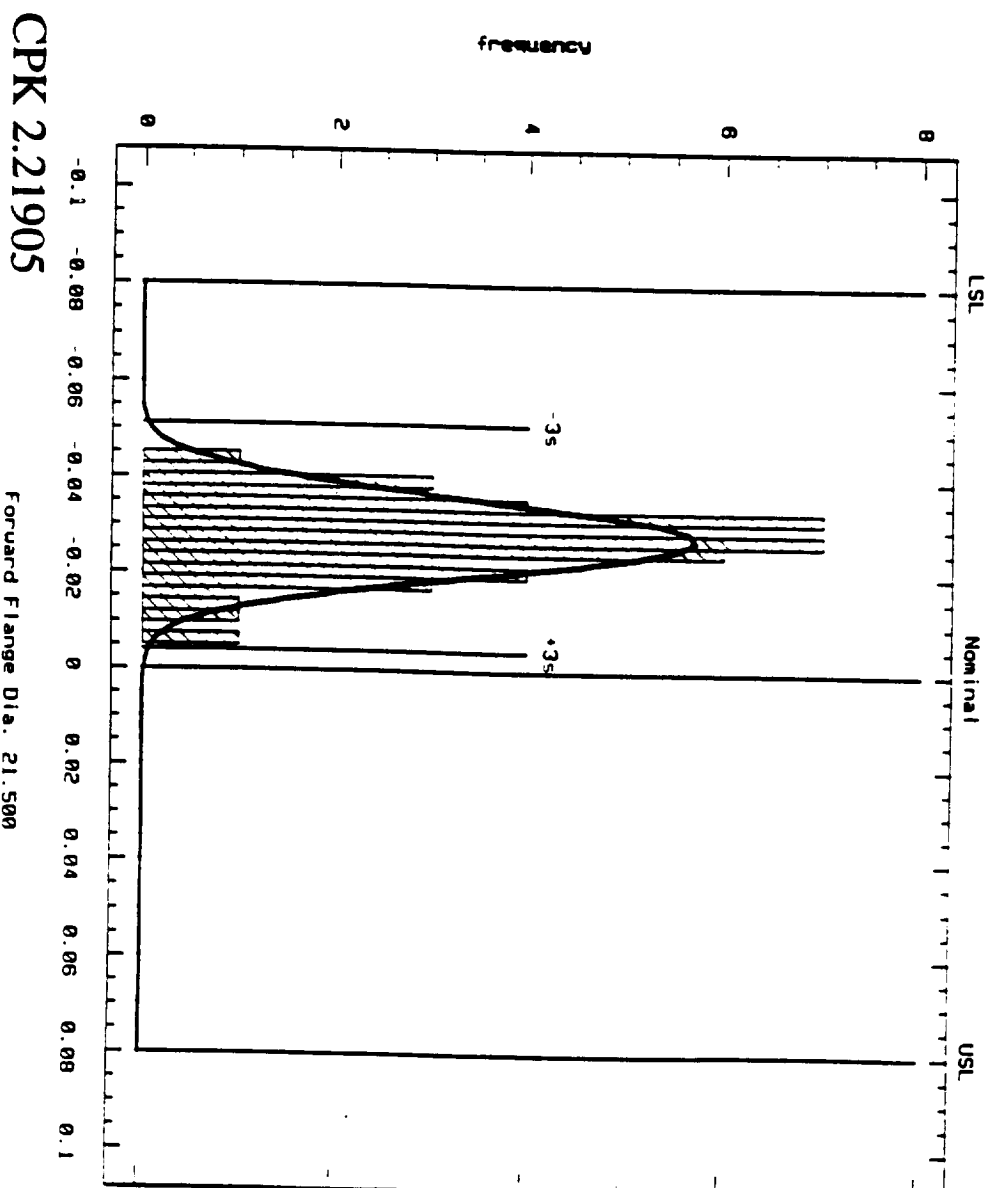
**PCC**

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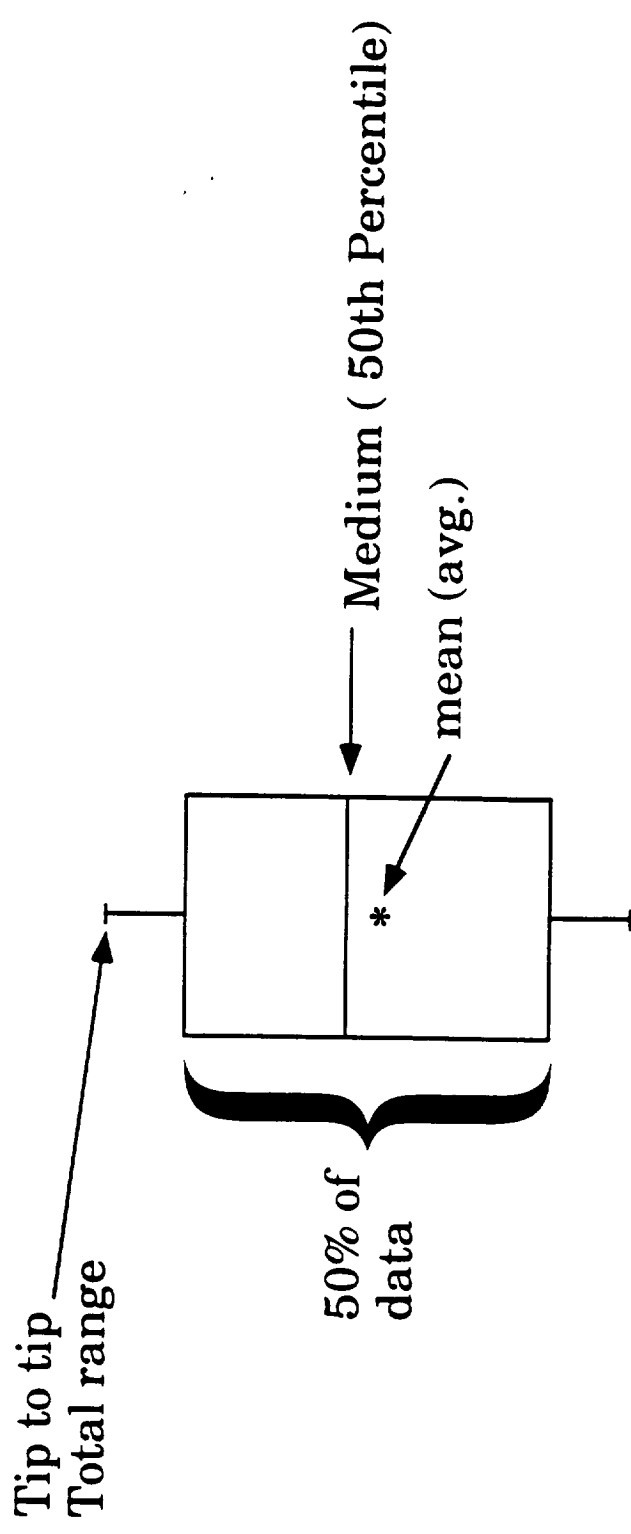
**NASA**



# PROCESS CAPABILITY FORWARD FLANGE DIA. 21.500 LOTS 17, 20, 21, & 22

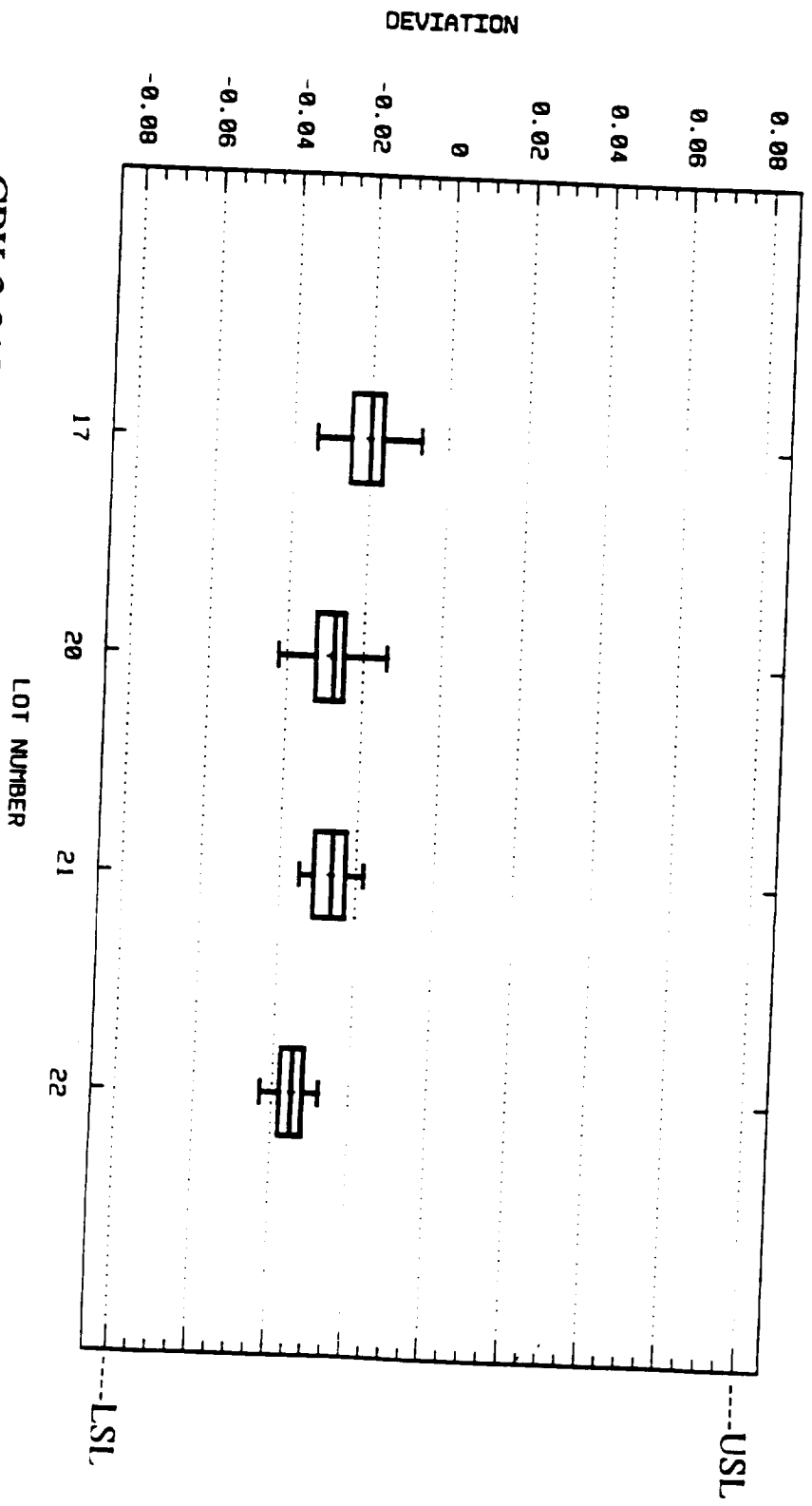


# STATISTICAL PROCESS CONTROL BOX AND WHISKER SYMBOL DEFINITION



\* All data analyzed by Statgraphics

# MULTIPLE BOX AND WHISKER PLOT FORWARD FLANGE DIA. 21.500 LOTS 17, 20, 21, & 22



CPK 2.21905

# PROCESS CAPABILITY ANALYSIS FORWARD FLANGE DIA. 21.500 LOTS 17, 20, 21, & 22

Specification:

Upper 0.08  
 Nominal 0  
 Lower -0.08

Normal distribution:

Count 48  
 \* Mean -0.0276042  
 \* Sigma 0.0078706

6.0 sigma limits:

+3.0 sigma -0.00399236  
 Mean -0.0276042  
 -3.0 sigma -0.051216

Observed beyond spec.:

High 0.000 %  
 Low 0.000 %  
 -----  
 Total 0.000 %

Estimated beyond spec.:

High 0.000 %  
 Low 0.000 %  
 -----  
 Total 0.000 %

Capability indices:

CP 3.38814  
 CR 0.295148  
 CPK 2.21905  
 (upper) 4.55722  
 (lower) 2.21905  
 K -0.345052  
 CPM 0.920006

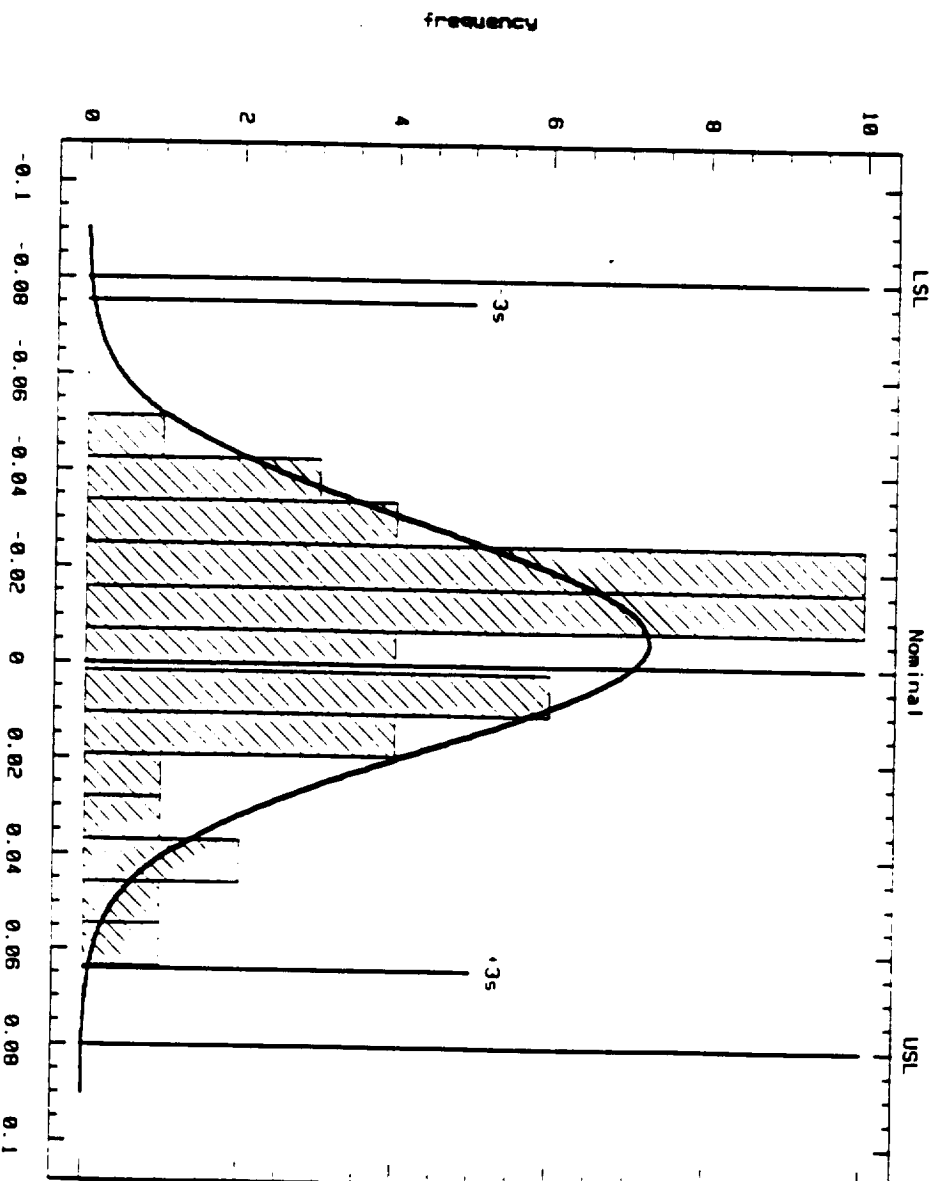
\* estimated parameter



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# PROCESS CAPABILITY FORWARD FLANGE TO -A- 16.850 LOTS 17, 20, 21, & 22

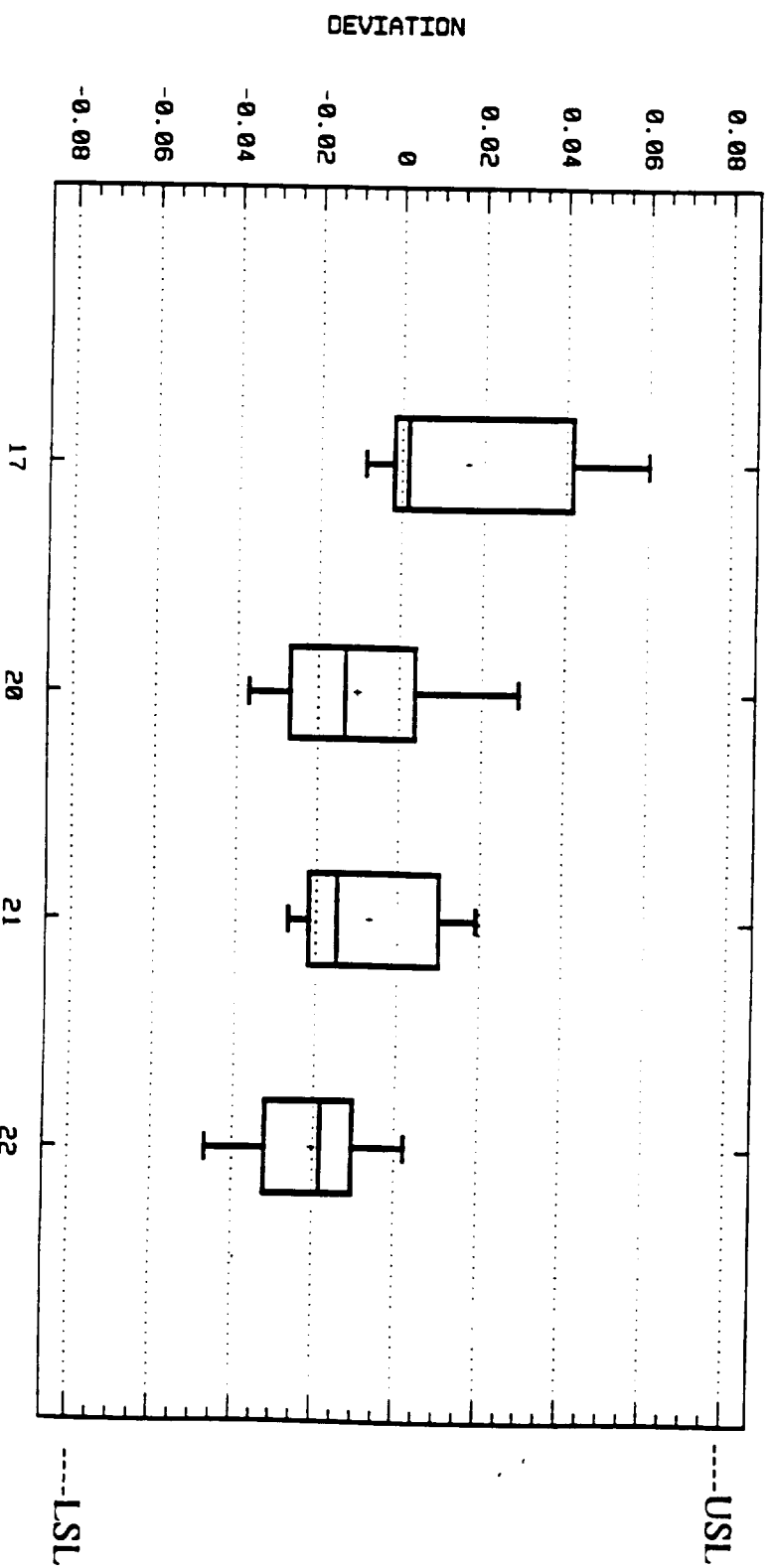


CPK 1.06747

**PCP** Precision Castparts Corp.

**NASA**

# MULTIPLE BOX AND WHISKER PLOT FORWARD FLANGE TO -A- 16.850 LOTS 17, 20, 21, & 22



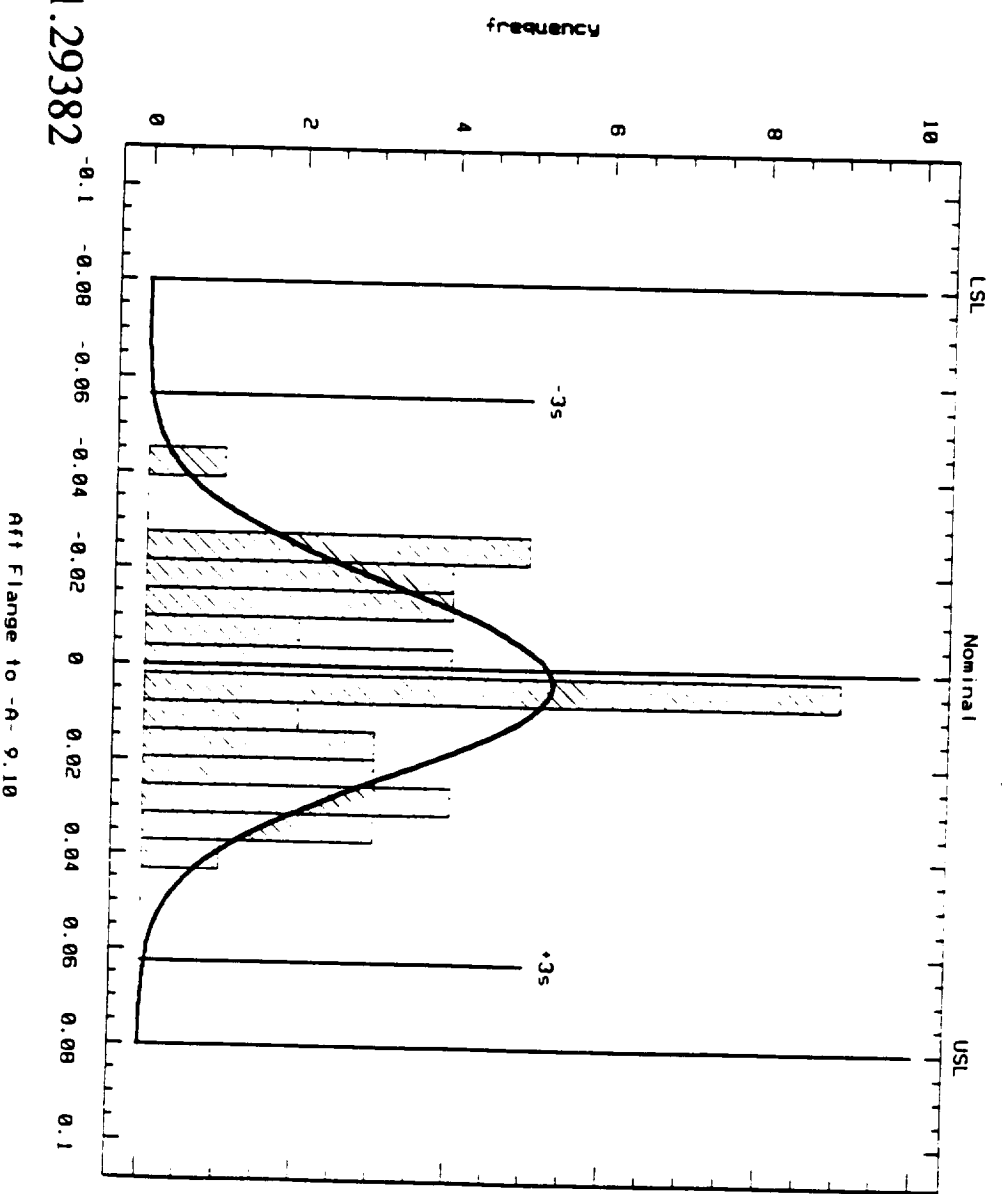
CPK 1.06747

# PROCESS CAPABILITY ANALYSIS FORWARD FLANGE TO -A- 16.850 LOTS 17, 20, 21, & 22

Specification:		Normal distribution:		6.0 sigma limits:	
Upper	0.08	Count	48	+3.0 sigma	0.0640896
Nominal	0	* Mean	-0.00560417	Mean	-0.00560417
Lower	-0.08	* Sigma	0.0232313	-3.0 sigma	-0.0752979
Observed beyond spec.:		Estimated beyond spec.:		Capability indices:	
High	0.000 %	High	0.011 %	CP	1.14788
Low	0.000 %	Low	0.068 %	CR	0.871172
-----		-----		CPK	1.06747
Total	0.000 %	Total	0.080 %	(upper)	1.22829
				(lower)	1.06747
				K	-0.0700521
				CPM	1.11522

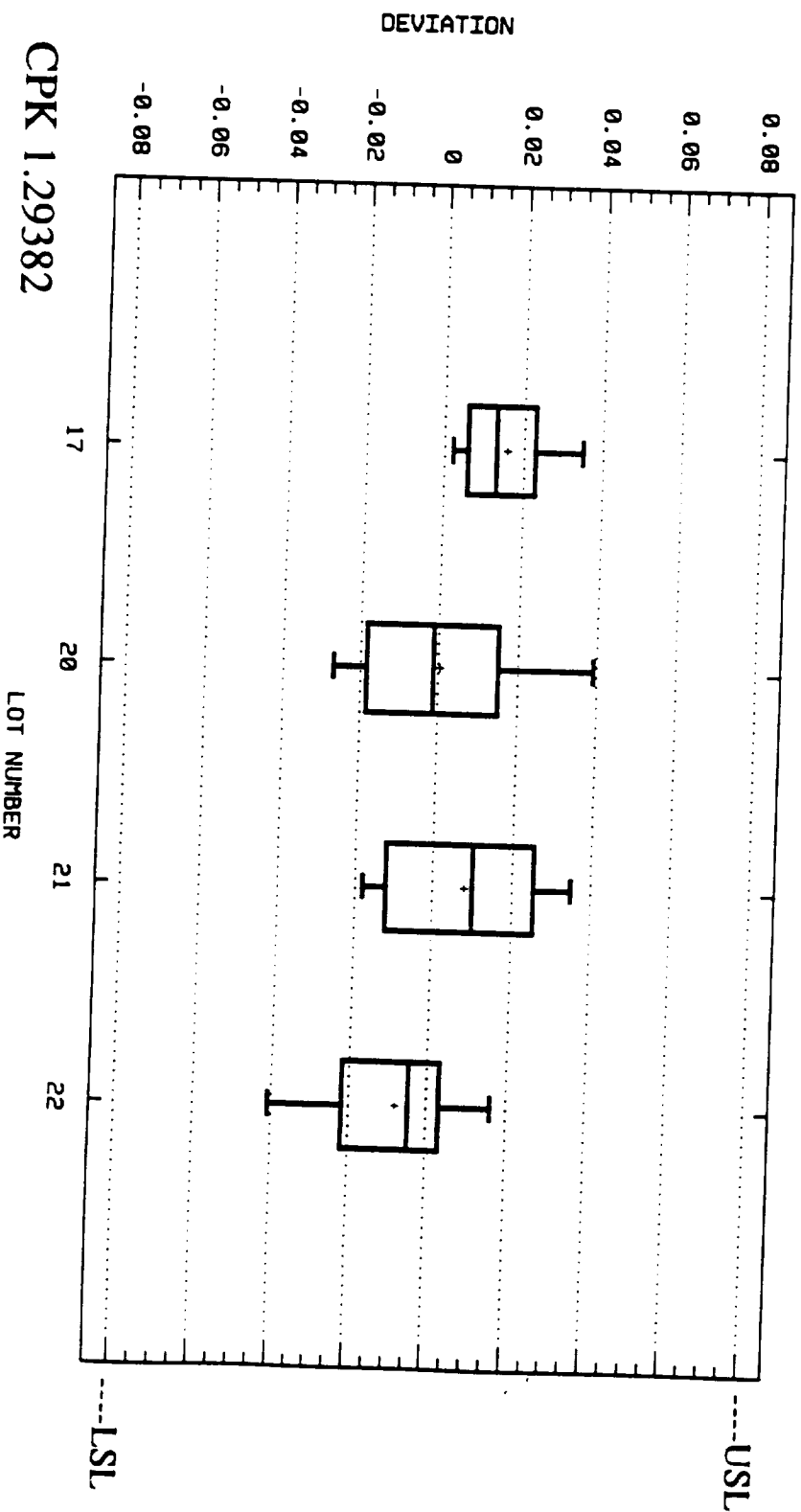
\* estimated parameter

# PROCESS CAPABILITY AFT FLANGE TO -A- 9.100 LOTS 17, 20, 21, & 22





# MULTIPLE BOX AND WHISKER PLOT AFT FLANGE TO -A- 9.100 LOTS 17, 20, 21, & 22



# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE TO -A- 9.100

### LOTS 17, 20, 21, & 22

#### Specification:

Upper 0.08  
 Nominal 0  
 Lower -0.08

#### Normal distribution:

Count 45  
 \* Mean 0.00304444  
 \* Sigma 0.0198265

#### 6.0 sigma limits:

+3.0 sigma 0.0625239  
 Mean 0.00304444  
 -3.0 sigma -0.056435

#### Observed beyond spec.:

High 0.000 %  
 Low 0.000 %  
 -----  
 Total 0.000 %

#### Estimated beyond spec.:

High 0.005 %  
 Low 0.001 %  
 -----  
 Total 0.007 %

#### Capability indices:

CP 1.345  
 CR 0.743493  
 CPK 1.29382  
 (upper) 1.29382  
 (lower) 1.39619  
 K 0.0380556  
 CPM 1.32907

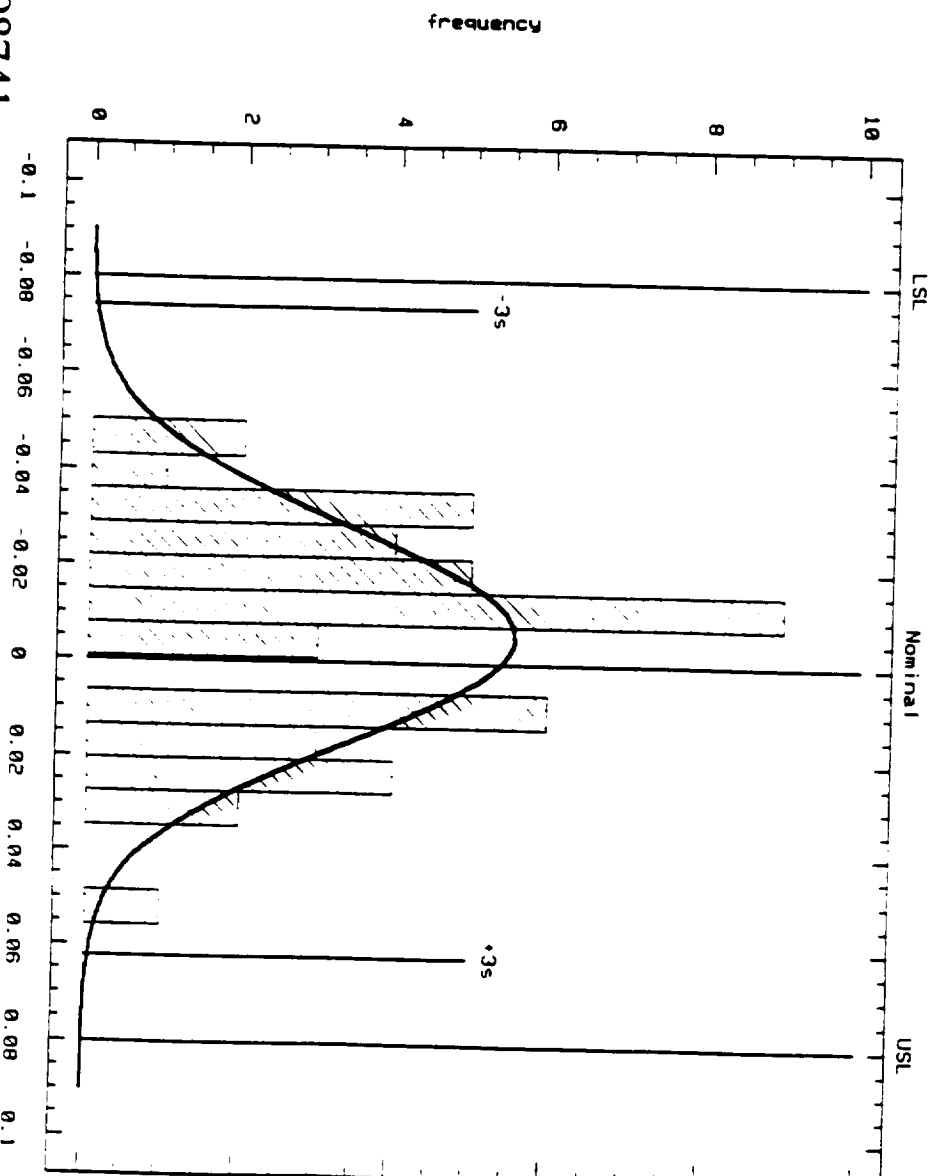
\* estimated parameter



Precision Castparts Corp.



# PROCESS CAPABILITY AFT FLANGE DIA. 23.890 LOTS 17, 20, 21, & 22



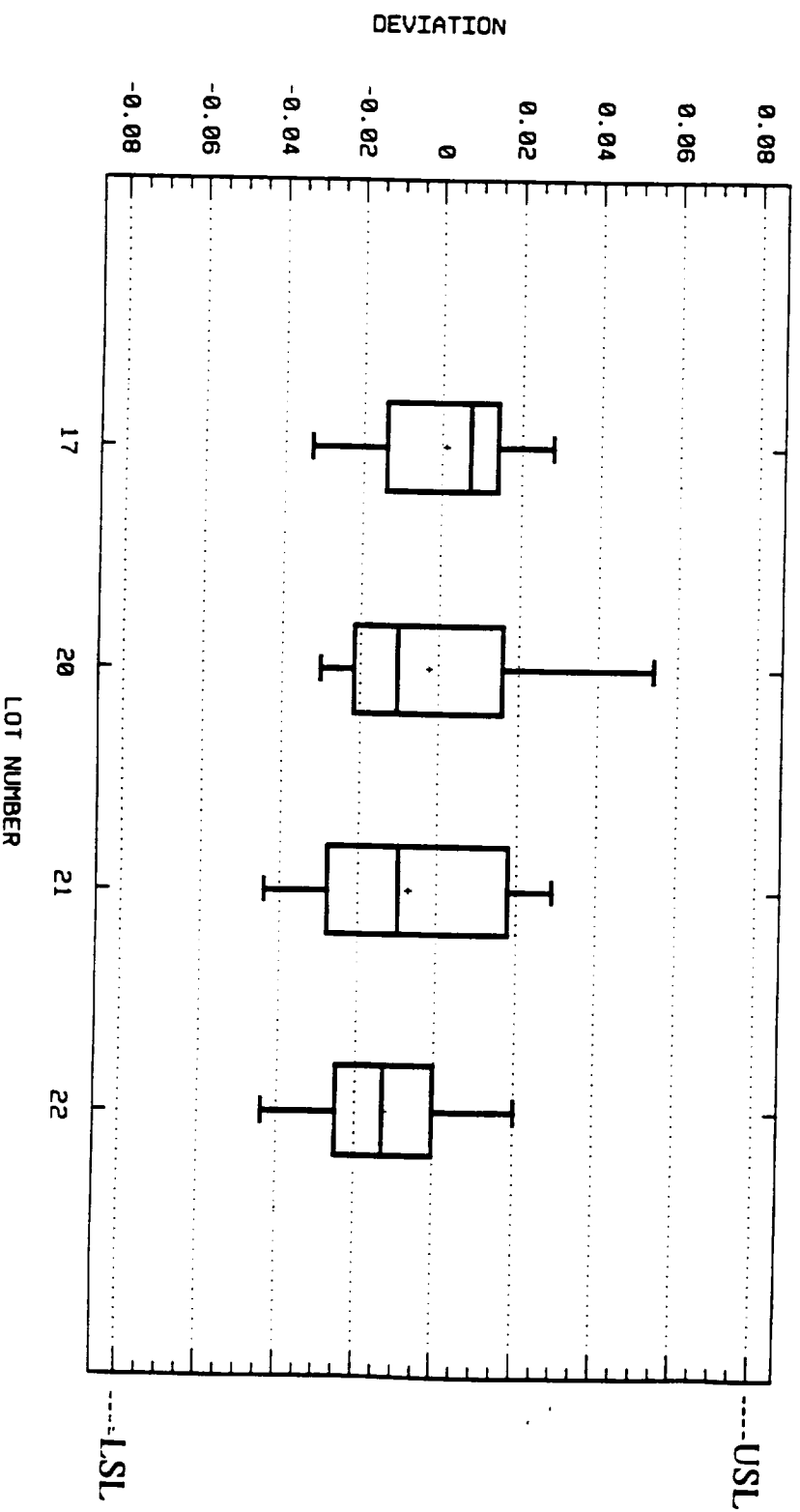
CPK 1.08741



Precision Castparts Corp.



# MULTIPLE BOX AND WHISKER PLOT AFT FLANGE DIA. 23.890 LOTS 17, 20, 21, & 22



CPK 1.08741

# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE DIA. 23.890

### LOTS 17, 20, 21, & 22

#### Specification:

Upper 0.08  
Nominal 0  
Lower -0.08

#### Normal distribution:

Count 45  
\* Mean -0.00588889  
\* Sigma 0.0227179

#### 6.0 sigma limits:

+3.0 sigma 0.0622647  
Mean -0.00588889  
-3.0 sigma -0.0740425

#### Observed beyond spec.:

High 0.000 %  
Low 0.000 %  
-----  
Total 0.000 %

\* estimated parameter

#### Estimated beyond spec.:

High 0.008 %  
Low 0.055 %  
-----  
Total 0.063 %

#### Capability indices:

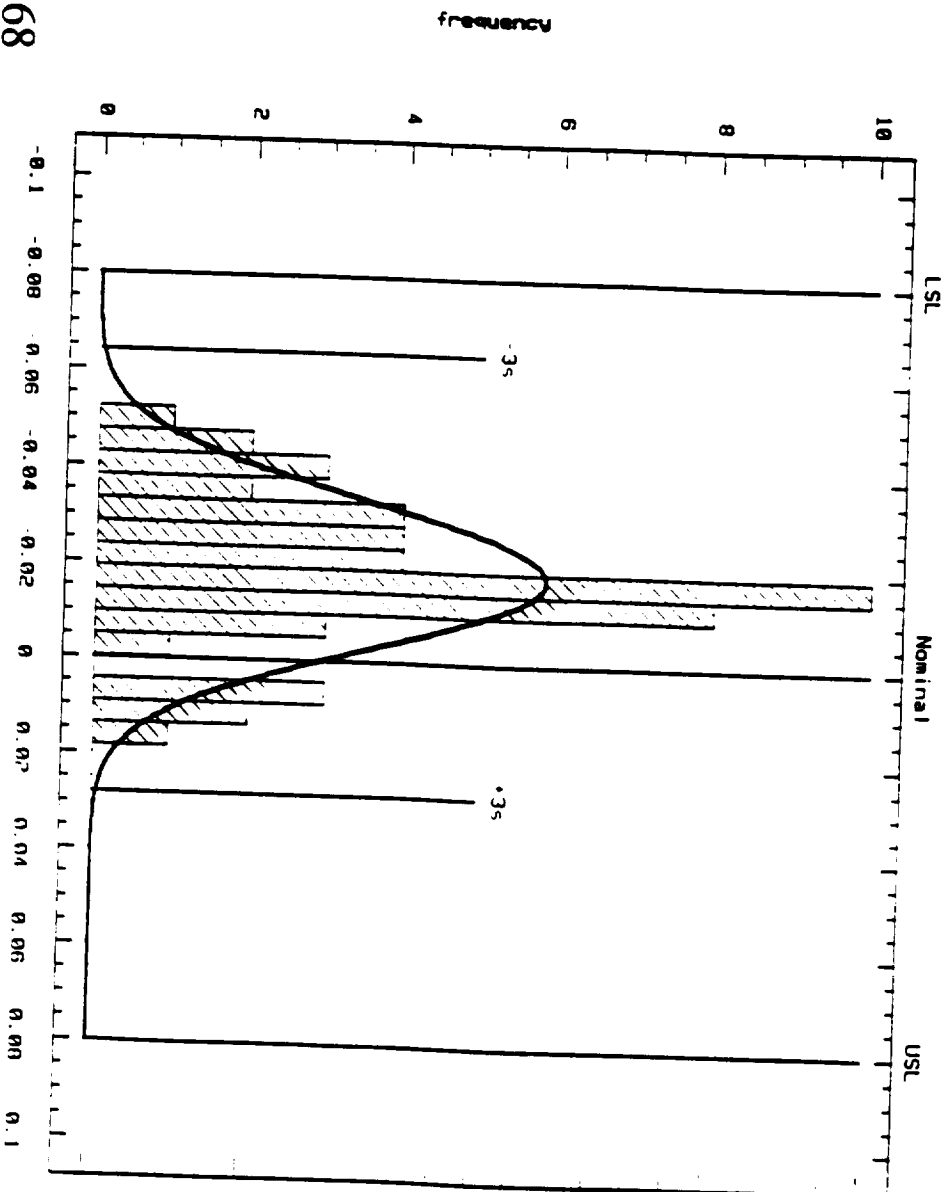
CP 1.17382  
CR 0.85192  
CPK 1.08741  
(upper) 1.26023  
(lower) 1.08741  
K -0.0736111  
CPM 1.13545



Precision Castparts Corp.



# PROCESS CAPABILITY AFT FLANGE DIA. 26.370 LOTS 17, 20, 21, & 22



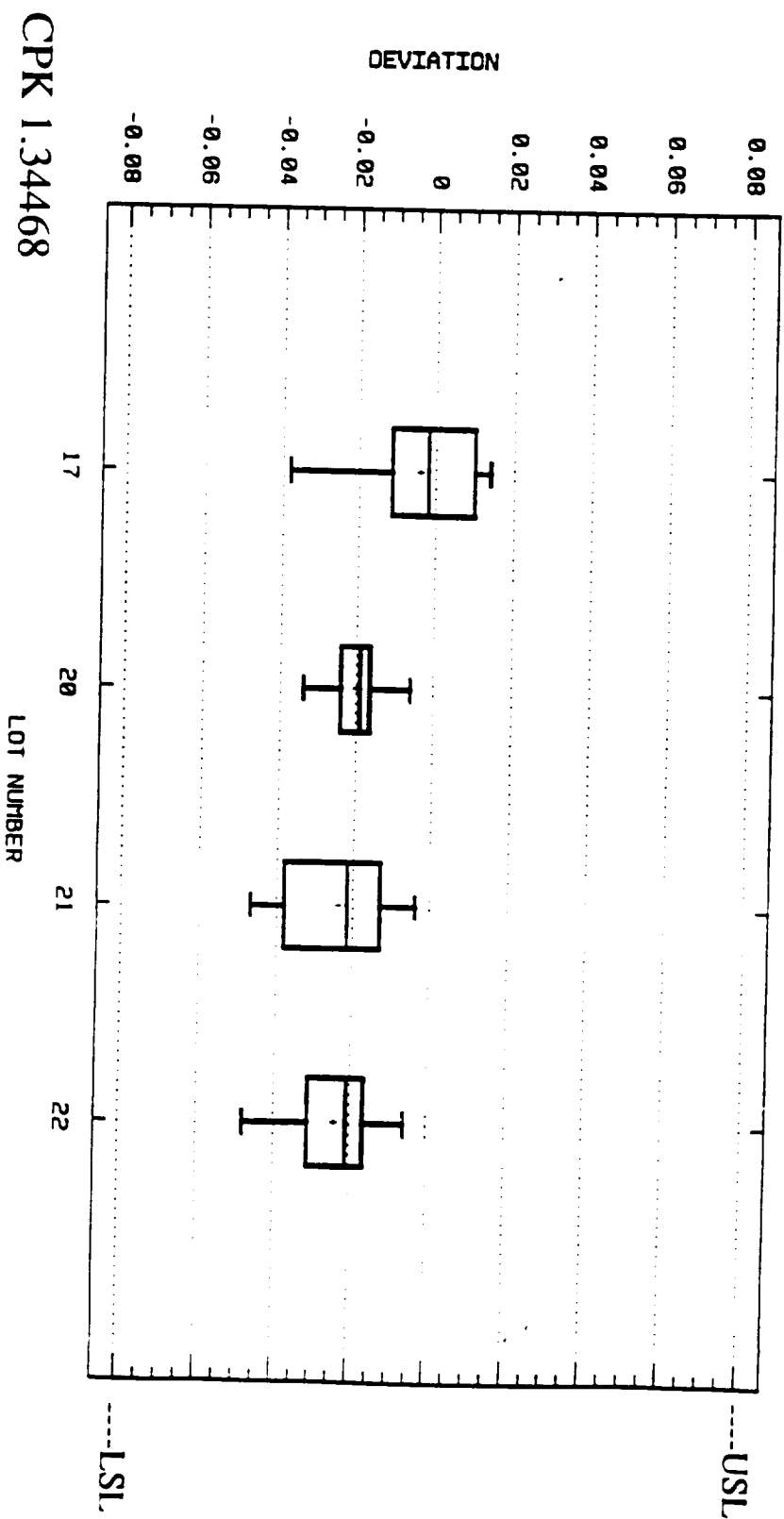
CPK 1.34468

Aft Flange Dia. 26.370

**PC** Precision Castparts Corp.

**WSA**

# MULTIPLE BOX AND WHISKER PLOT AFT FLANGE DIA. 26.370 LOTS 17, 20, 21, & 22



# PROCESS CAPABILITY ANALYSIS

## AFT FLANGE DIA. 26.370

### LOTS 17, 20, 21, & 22

Specification:		Normal distribution:		6.0 sigma limits:	
Upper	0.08	Count	48	+3.0 sigma	0.0278896
Nominal	0	* Mean	-0.018125	Mean	-0.018125
Lower	-0.08	* Sigma	0.0153382	-3.0 sigma	-0.0641396
Observed beyond spec.:		Estimated beyond spec.:		Capability indices:	
High	0.000 %	High	0.000 %	CP	1.73858
Low	0.000 %	Low	0.003 %	CR	0.575183
-----		-----		CPK	1.34468
Total	0.000 %	Total	0.003 %	(upper)	2.13247
				(lower)	1.34468
				K	-0.226563
				CPM	1.11619
* estimated parameter					

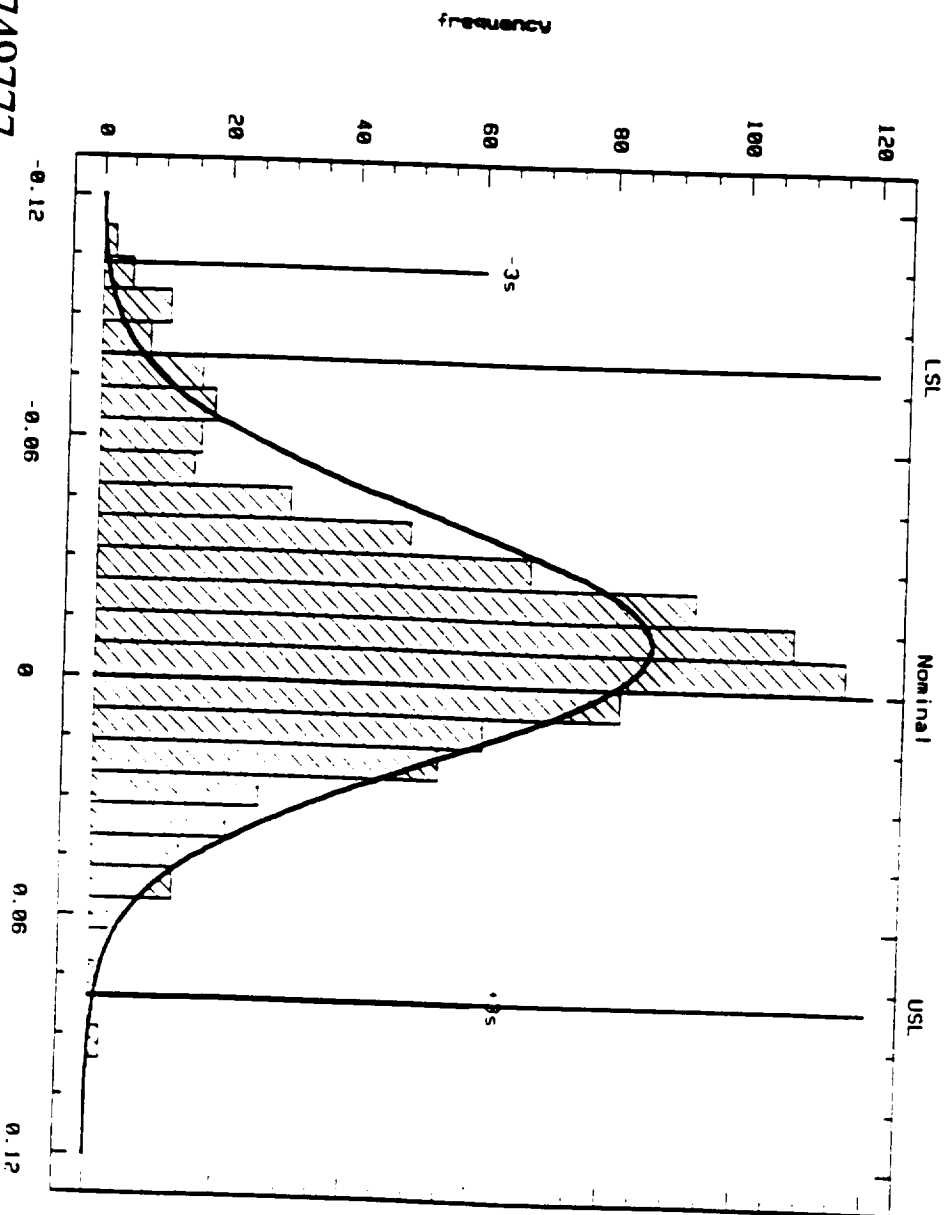


Precision Castparts Corp.





# PROCESS CAPABILITY OD JACKET PROFILE 0.160 LOTS 17, 20, 21, & 22



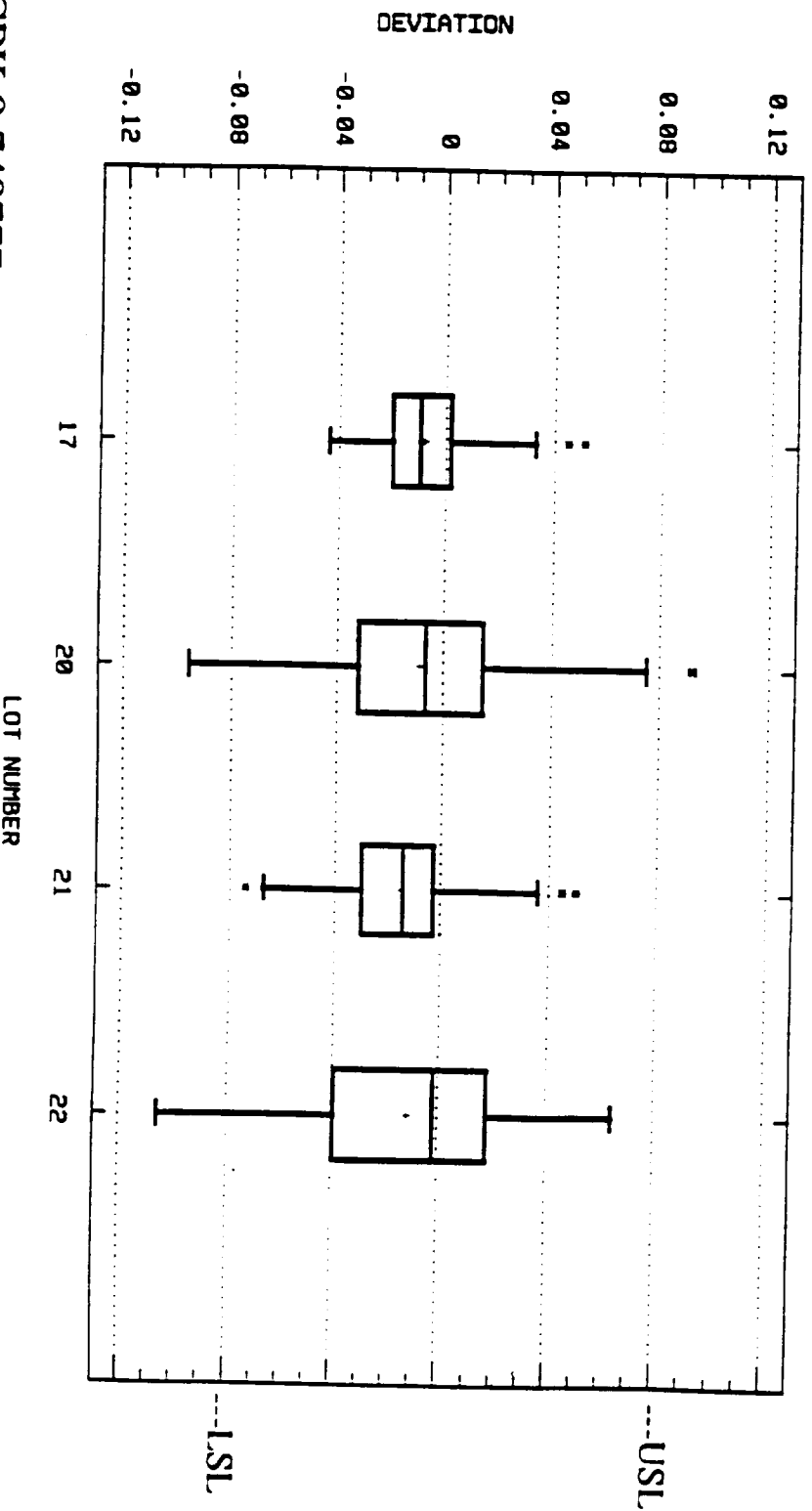
CPK 0.749777

Outside Jacket Profile .160 to nbc

**PCP** Precision Castparts Corp.

**WASA**

# MULTIPLE BOX AND WHISKER PLOT OD JACKET PROFILE 0.160 LOTS 17, 20, 21, & 22



CPK 0.749777

# PROCESS CAPABILITY ANALYSIS

## OD JACKET PROFILE 0.160

### LOTS 17, 20, 21, & 22

Specification:	Normal distribution:		6.0 sigma limits:	
Upper 0.08	Count	832	+3.0 sigma	0.0805337
Nominal 0	* Mean	-0.0112115	Mean	-0.0112115
Lower -0.08	* Sigma	0.0305817	-3.0 sigma	-0.102957
Observed beyond spec.:	Estimated beyond spec.:		Capability indices:	
High 0.240 %	High	0.143 %	CP	0.87198
Low 3.125 %	Low	1.225 %	CR	1.14682
-----	-----	-----	CPK	0.749777
Total 3.365 %	Total	1.368 %	(upper)	0.994183
			(lower)	0.749777
			K	-0.140144
			CPM	0.818638

\* estimated parameter



Precision Castparts Corp.



## **CHALLENGES**

- **Checking wall thickness after patches are welded in**
  - **Special designed wall thickness gauges**
  - **Last Patch**
- **Measuring Mismatch**
  - **Developing A CMM Program**
- **Close control of the thickness of the patches**



***Precision Castparts Corp.***



# RECOMMENDATIONS

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- One piece tool for jacket would reduce dimensional variability caused by pattern assembly.



*Precision Castparts Corp.*



# INSPECTION IDENTIFICATION & REJECTION CRITERIA

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Steve Irvine

- Reliable and accurate inspection techniques have been developed for AMCC casting.



*Precision Castparts Corp.*



# INSPECTION IDENTIFICATION & REJECTION CRITERIA

---

Steve Irvine

- Process Router
- Technique Cards



*Precision Castparts Corp.*



# 20013 Processing

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Wax Molding

Wax Cleaning & Assembly

♦ Wax Dimensional/CMM

Investing

Casting

Shell Removal

Gate Removal



*Precision Castparts Corp.*





# 20013 Processing

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## Post HIP Processing

- ◆ 1st. Visual
- ◆ 1st. FPI

## HIP

## Post HIP Processing

- ◆ 2nd. FPI
- ◆ 2nd. Visual
- ◆ 100% X-ray



*Precision Castparts Corp.*



# 20013 Processing

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## Patch Welding

- ◆ 1st. Dimensional
- ◆ 2nd. Dimensional
- ◆ Patch FPI
- ◆ Patch X-ray

## HIP

## Heat Treat



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# 20013 Processing

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## Final Processing

- ◆ Final FPI
- ◆ 3rd. Dimensional
- ◆ 3rd. Visual
- ◆ CMM / Target

Ship

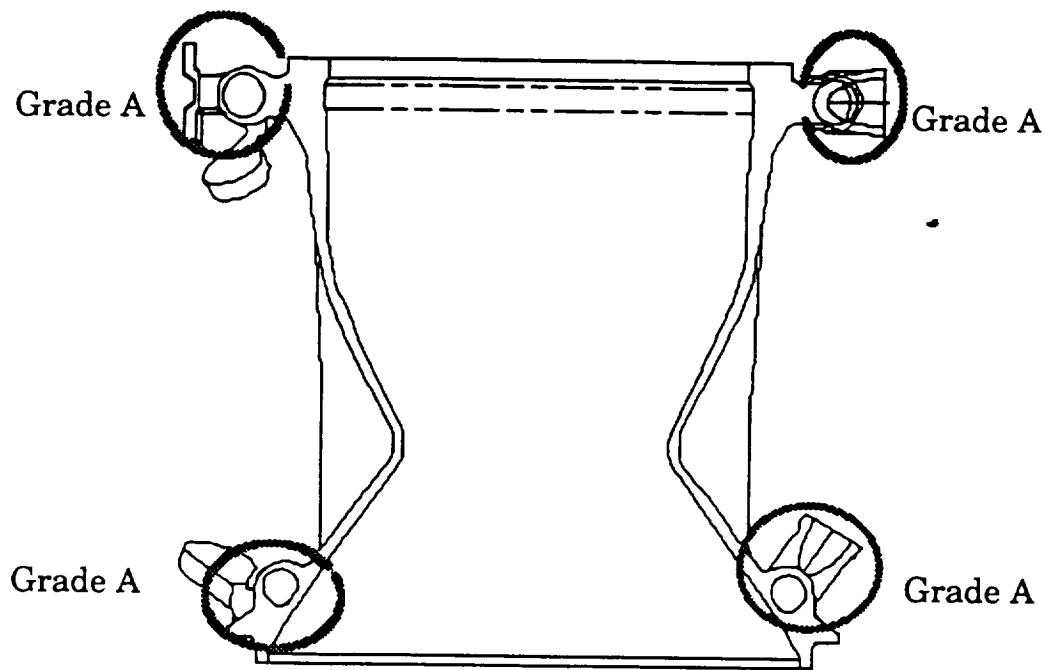


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USING DEPARTMENT: <u>Visual</u>		FIXED PROCESS REV: N/A	
PRECISION CASTPARTS CORP. <b>QUALITY STANDARD</b>		OPERATION NO. 2.561.0 / 2.562.0 & 2.563.0	PCC PART NO. <b>20013</b>
CUSTOMER <b>NASA</b>	CUSTOMER DWG. NO. <b>96M66441</b>	B/P REV. —	PART NAME <b>AMCC</b>
TECH CARD REV. NO. 1		TECH CARD REV. NO. 2	TECH CARD REV. NO.
APPROVALS: AUTHOR	PWright 11/23/92	<i>PWright</i> 10/7/93 PWright 10/7/93	
ENGINEER		<i>B. Miller</i> 10.7.93	
N.D.T. ENGINEER		<i>R.E. Aldridge</i> 10/18/93	
MFG. TEAM REP.		<i>[Signature]</i> 10.20.93	
Q.A. ENGINEER		<i>B. Hughes</i> 10/7/93	
MATERIAL TYPE SPECIFICATION <b>JBK 75</b>		HEAT TREATMENT / SPECIFICATION <b>Homogenize, Anneal, &amp; Age</b>	
WELD REPAIR SPECIFICATION <b>PCP 59-003</b>		WELD MAPS YES <input checked="" type="checkbox"/> NO <input type="checkbox"/>	FREQUENCY OF INSPECTION <b>100%</b>
SPECIFICATIONS APPLICABLE TO THIS OPER. <b>QCM 9.1.5 AND SUBSETS</b>		MRB FORM / PROCEDURE <b>N/A</b>	SOURCE INSPECTION YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>
<b>NO CRACKS, LAPS, COLD SHOT/SHUT OR LINEAR (L=3xW) TYPE INDICATIONS ALLOWED, EXCEPT AS NOTED.</b>			
SURFACE FINISH: <b>RMS 125</b>	GATE REF: <b>+ .030" All Surfaces</b>	PARTING LINES: <b>+ .005 - .000 none allowed in Grade A</b>	UNINTERPRETABLES:
SCALE ALLOWED: <input type="checkbox"/> YES <input checked="" type="checkbox"/> NO			
POSITIVES: <b>Max .020 Grade A &amp; B External (height, depth and diameter) None Allowed Grade A Internal</b>			
NEGATIVES: <b>.020" Grade B (height, depth and diameter) None Allowed Grade A</b>			
BLENDING LIMITS: <b>Within Blueprint Tolerance</b>			
WELD REPAIR LIMITS: <b>Unlimited Welding Allowed</b>			
H.T. AFTER WELD REPAIR: <b>Yes Anneal / Age</b>			
COMMENTS: <b>Weld Drop thru Grade A Internal. .020" max.</b>			

USING DEPARTMENT: VISUAL		FIXED PROCESS REV: N/A
PRECISION CASTPARTS CORP.		PCC PART NO.
QUALITY STANDARD		20013
	TECH CARD REV. NO. 2	TECH CARD REV. NO.
		TECH CARD REV. NO.

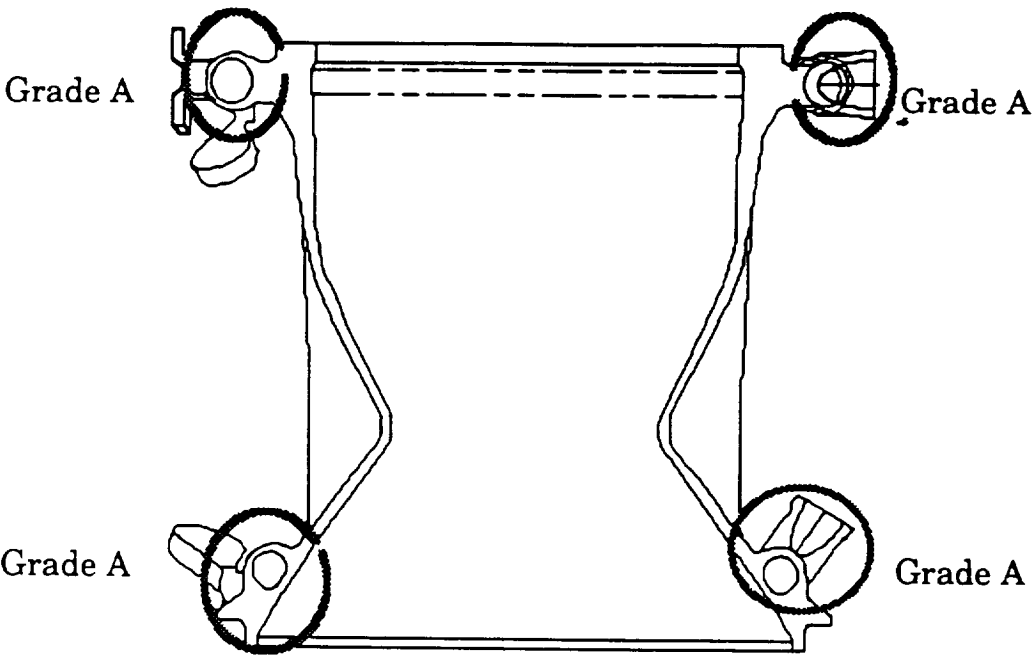


Grade A ———

Balance of part Grade B

USING DEPARTMENT: X-Ray Re: _____				FIXED PROCESS REV: N/A			
PRECISION CASTPARTS CORP. <b>QUALITY STANDARD</b>				OPERATION NO. 2.591.1 / 2.601.0			
CUSTOMER <b>NASA</b>		CUSTOMER DWG. NO. 96M66441		B/P REV. _____		PCC PART NO. <b>20013</b>	
		TECH CARD REV. NO. 0		TECH CARD REV. NO. 1		PART NAME AMCC	
APPROVALS: AUTHOR		PWright 10/23/92		PWright 10/9/93 10/9/93		TECH CARD REV. NO.	
ENGINEER				D. Nielsen 10-18-93			
LEVEL III				R. H. Frost 10-19-93			
MFG. TEAM REP.				J. D. Swann 10/21/93			
Q.A. ENGINEER				J. Wall 10/11/93			
MATERIAL TYPE SPECIFICATION JBK 75				HEAT TREATMENT / SPECIFICATION Homogenize, Anneal, & Age / Statement of work			
WELD REPAIR SPECIFICATION PCP 59-003				WELD MAPS YES <input checked="" type="checkbox"/> NO <input type="checkbox"/>		FREQUENCY OF INSPECTION 100%	
SPECIFICATIONS APPLICABLE TO THIS OPER. QCM 9.1.7 AND SUBSETS				MRB FORM / PROCEDURE N/A		SOURCE INSPECTION YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>	
NO CRACKS, LAPS, COLD SHOT/SHUT OR LINEAR (L=3 x W) TYPE INDICATIONS ALLOWED.							
INTERPRET PER: ASTM E 192 REF. RADIOGRAPHS							
AREA	A			B			Patches
SECTION THICKNESS	1/8"	3/8"	3/4"	1/8"	3/8"	3/4"	1/8" 3/8" 3/4" 1/8" 3/8" 3/4"
GAS HOLES	N/A	3	4	N/A	4	5*	N/A 2 N/A
FOREIGN MAT (L.D.)	N/A	3	4	N/A	4	5	N/A 2 N/A
FOREIGN MAT (M.D.)	N/A	N/A	N/A	N/A	N/A	N/A	N/A N/A N/A
SHRINKAGE, SPONGE	N/A	N/A	1	N/A	1	3	N/A N/A N/A
SHRINKAGE, DENDRITIC	N/A	3	3	N/A	4	5	N/A 2 N/A
SHRINKAGE, CAVITY	N/A	N/A	N/A	N/A	N/A	N/A	N/A N/A N/A
SHRINKAGE, FILIMENTARY	N/A	N/A	N/A	N/A	N/A	N/A	N/A N/A N/A
WELD REPAIR LIMITS: Unlimited Weld				* Excluding the largest indication ≥ .750  <b>DO NOT USE HOOKS OR CHAINS ON THIS PART</b>			
HEAT TREATMENT AFTER WELD: Solution / Age							
APPLICABLE NOTES: <div style="display: flex; justify-content: space-between;"> <div> <input checked="" type="checkbox"/> WHEN TWO OR MORE TYPES OF DISCONTINUITIES ARE PRESENT TO AN EXTENT EQUAL TO OR NOT SIGNIFICANTLY BETTER THAN THE ACCEPTANCE STANDARDS FOR RESPECTIVE DISCONTINUITIES, THE PARTS SHALL BE REJECTED.   <input type="checkbox"/> GAS HOLES OR SAND SPOTS AND INCLUSIONS ALLOWED BY THIS CHART SHALL BE CAUSE FOR REJECTION WHEN CLOSER THAN TWICE THEIR MAXIMUM DIMENSION TO AN EDGE OR EXTREMITY OF A FINISHED CASTING.   <input checked="" type="checkbox"/> OTHER:         </div> <div> <input checked="" type="checkbox"/> MARK FILM WITH: GREASE PENCIL   <input type="checkbox"/> PENTEL   <input type="checkbox"/> MARK ALL IND. ON FILM   <input type="checkbox"/> MARK IND. PER Q.C.M. 9.1.7   <input type="checkbox"/> OTHER         </div> </div>							

USING DEPARTMENT:		FIXED PROCESS REV: N/A	
PRECISION CASTPARTS CORP.		OPERATION NO.	PCC PART NO.
QUALITY STANDARD		2.591.1 / 2.601.0	20013
	TECH CARD REV. NO. 1	TECH CARD REV. NO.	TECH CARD REV. NO.



Grade A ———

Balance of part Grade B

USING DEPARTMENT: PENETRANT		FIXED PROCESS REV: N/A	
PRECISION CASTPARTS CORP. <b>QUALITY STANDARD</b>		OPERATION NO. 2.571.1 / 2.571.2 / 2.572.2 2.573.2 / 2.573.4 / 2.573.5 / 2.575.0	PCC PART NO. <b>20013</b>
CUSTOMER NASA	CUSTOMER DWG. NO. 96M66441	B/P REV. _____	PART NAME AMCC
APPROVALS:	TECH CARD REV. NO. 2	TECH CARD REV. NO. 3	TECH CARD REV. NO.
AUTHOR	PWRIGHT 11/12/92	<i>P. Wright</i> 10/9/93	
ENGINEER		<i>B. Miller</i> 10-15-93	
LEVEL III		<i>David H. Hoos</i> 10-19-93	
MFG. TEAM REP.		<i>M. Chase</i> 10-21-93	
Q.A. ENGINEER		<i>Full</i> 10/11/93	
MATERIAL TYPE/SPECIFICATION JBK 75 / State of work Table 1 for casting specifications		HEAT TREATMENT / SPECIFICATION Homogenize, Anneal, & Age / Statement of work	
WELD REPAIR SPECIFICATION PCP 59-003		WELD MAPS YES <input checked="" type="checkbox"/> NO <input type="checkbox"/>	FREQUENCY OF INSPECTION • 100%
SPECIFICATIONS APPLICABLE TO THIS OPER. QCM 9.1.5 AND SUBSETS		MRB FORM / PROCEDURE N/A	SOURCE INSPECTION YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>
NO CRACKS, LAPS, COLD SHOT/SHUTS OR LINEAR (L=3xW) TYPE INDICATIONS ALLOWED.			
PENETRANT Level 3	DWELL TIME 30 - 90 minutes	DEVELOPER Dry Non-Aqueous	
MICROSHRINKAGE. LIMITS:			

No Micro Shrinkage Allowed.

INDICATIONS NON-INTERPRETABLE:  $\leq .032$  Including linears

INDICATIONS ALLOWED: Inspect to Q.S. 501 for FPI Black light only

	CRITICAL *	STANDARD
Discreet	Single negative discontinuities, four (4) non linear discontinuities to .045" $\phi$ in a 1" sq and separated from each other by twice the size of the larger adjacent indication.	Four (4) non linear discontinuities to .075" $\phi$ in a 1" sq and separated from each other by twice the size of the larger adjacent indication.
Cluster	Clustered negative discontinuities, none allowed	1 non linear cluster to .500" in any 2" sq. Each indication to be no greater than .045" $\phi$ and separated from each other by twice the size of the larger adjacent indication.

BLENDING LIMITS:

See Salvage Tech Card

WELD REPAIR LIMITS:

None

Unlimited weld

H.T. AFTER WELD:

Yes

Anneal / Age

COMMENTS:

- Do not use hooks or chains on this part.

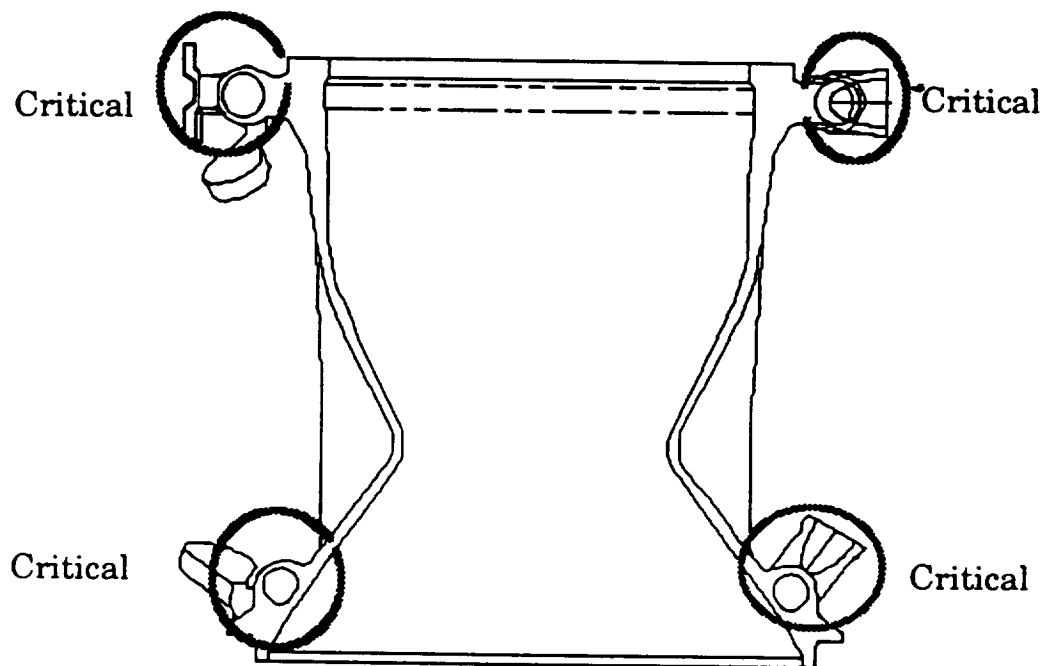
On final Penetrant, Blacklight Borescopic Inspection required.

\* Critical applies to the marked areas, see map page 2, and the patches.

• Use the Grinding/Salvage Fixture to process the part down the FPI line (the fixture is located in Team 5's fixture holding area)



USING DEPARTMENT: <b>PENETRA</b>		FIXED PROCESS REV: N/A
PRECISION CASTPARTS CORP.		PCC PART NO.
<b>QUALITY STANDARD</b>		<b>20013</b>
	TECH CARD REV. NO. 2	TECH CARD REV. NO. 3
		TECH CARD REV. NO.



Critical ———

Balance of part Standard

# SUMMARY

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Steve Irvine

- PCC has a demonstrated ability to produce the AMCC casting to NASA specifications.



*Precision Castparts Corp.*



3/29/95

## AMCC CASTING DEVELOPMENT FINAL REPORT

### **DR-07 Casting Specification**

PCC has determined that the AMCC casting (NASA dwg. #96M66441 / PCC P/N 20013) is fully castable in its current form. PCC strongly recommends that all castings produced from JBK-75 be designed, as this part was, with an FPI non-interpretable level of .032" in diameter. PCC recommends construction of a one piece tool, to form the jacket area of the casting, to enable PCC to meet the jacket profile from datums criteria. The other alternative to this would be relaxation of the criteria on the blueprint. The mis-match requirement for the manifold patches as currently called out on the drawing is not within the process capability of this casting. PCC recommends that NASA & PCC concurrently engineer a resolution to this dimensional non-conformance.

2 September 1994

In reply to CDR-91-NASA-AMCC

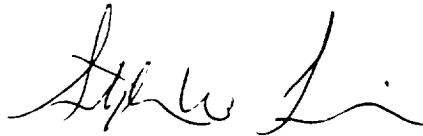
NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting  
Development (AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

We are transmitting data required by contract for your information and retention.

Sincerely,



Steve Irvine  
Program Manager  
Rocket Engineer & Space Component Development Engineering Program  
PRECISION CASTPARTS CORP.

SW/jld  
LSBO/6581  
NASA\quar.dec

cc: AP25B . . . . . 1 report & letter  
CN22D . . . . . 3 reports  
AT01 . . . . . 1 report  
EM15 . . . . . 1 report  
COTR (Code EP62) . . . 1 report & letter

NASA Scientific and Technical  
Information Facility . . . . . 2 reports  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090

1994

CDR-91-NASA-AMCC

NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 12

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

CDRL NO. 8

PREPARED BY

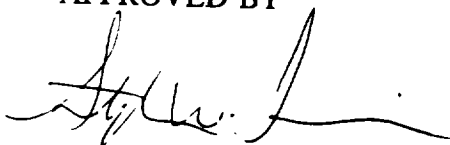
RICK SOLL  
Project Engineer



PAGE NUMBER

... 3

APPROVED BY



... 4

STEVE IRVINE

Program Manager

.... 5

cket Engine & Space Component Development Engineering Team

.... 5

.... 6

PRECISION CASTPARTS CORP.  
Large Structural Business Operation  
4600 S.E. Harney Drive  
Portland, Oregon 97206

ORIGINAL PAGE IS  
OF POOR QUALITY

## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main combustion Chamber (MCC).
- To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of eleven (11) castings.
- NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware. If the final castings are acceptable, they may be allocated to flight unit combustion chamber assemblies.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the thirty forth through thirty sixth months of the contract, for the period May 1994 through July 1994.

## **WORK PERFORMED**

### **Casting Lots 9, 10, 12, 14**

These four parts constituted the Gating DOE. Variations in gating were made on each casting based upon experience gained on the prior ones and also other input. Engineers not assigned to the program were invited to participate and several did. These castings were then examined with both X-ray and fluorescent penetrant, cut up and re-examined. The results indicated that the development process should proceed with the Process DOE. This will occur after the Design Review in October.

### **Casting Lots 15 & 16**

These two parts ran ahead of the process DOE in order to satisfy a need for hot fire testing. They were built up in wax to reflect the additional stock per the 96M66441 Rev. D blueprint. Lot 15 gating is basically the same as Lot 5, which was sound a part. Lot 16 gating benefitted from preliminary results on the Gating DOE castings. Both parts shipped in October 1993.

### **Casting Lots 5 & 7**

These castings were returned to us by Aerojet. Lot #5 required weld build, reheat treat and targeting and will be used to test liner installation. Lot 7 had enough stock, so did not require weld build, but was re-heat-treated and targeted. These parts ran as PCC P/N 93062, Lots 1 and 2 and shipped in August 1993. This work was outside the NASA contract, performed on Aerojet Purchase Orders.

## PROJECT STATUS

The process D.O.E. has been progressing smoothly. During the three month period all four lots completed processing. This includes all metallography and post chem mill evaluation. The team has met to to discuss P.D.R. format and set milestone for completion of package and presentation to NASA.

## PLAN FOR THE NEXT THREE MONTHS

- Complete P.D.R. package.
- Confirm a presentation date with NASA.



## PART STATUS - DEVELOPMENT ENGINEERING

Page 27

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

DATE STATUS

5/6/94

- Lot 17 -
- Lot 20 - All lots have been sent to chem mill.
- Lot 21 - And select sections sent to the lab.
- Lot 22 -

5/27/94

- Lot 17 -
- Lot 20 - All lots are due back from chem mill
- Lot 21 - and all lab work complete on 6/10/94.
- Lot 22 -

6/9/94

- Lot 17 -
- Lot 20 - All lots are back from chem mill
- Lot 21 - and are in NDT for FPI mapping.
- Lot 22 - All lab work is complete except grain size analysis.

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2 June 1994

In reply to CDR-91-NASA-AMCC

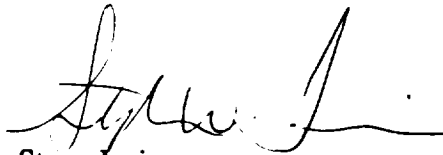
NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting  
Development (AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

We are transmitting data required by contract for your information and retention.

Sincerely,



Steve Irvine  
Program Manager  
Rocket Engineer & Space Component Development Engineering Program  
PRECISION CASTPARTS CORP.

SW/jld  
LSBO/6581  
NASA\quar.dec

cc: AP25B . . . . . 1 report & letter  
CN22D . . . . . 3 reports  
AT01 . . . . . 1 report  
EM15 . . . . . 1 report  
COTR (Code EP62) . . . 1 report & letter

NASA Scientific and Technical  
Information Facility . . . . . 2 reports  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090

2 June 1994

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 11

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

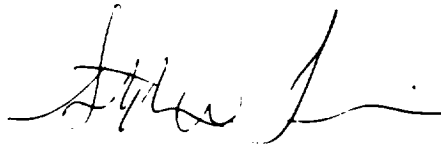
CDRL NO. 8

PREPARED BY

RICK SOLL  
Project Engineer



APPROVED BY



STEVE IRVINE  
Program Manager

Rocket Engine & Space Component Development Engineering Team

PRECISION CASTPARTS CORP.  
Large Structural Business Operation  
4600 S.E. Harney Drive  
Portland, Oregon 97206

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main combustion Chamber (MCC).
- To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of eleven (11) castings.
- NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware. If the final castings are acceptable, they may be allocated to flight unit combustion chamber assemblies.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the thirty first through thirty third months of the contract, for the period February 1994 through April 1994.

## **WORK PERFORMED**

### **Casting Lots 9, 10, 12, 14**

These four parts constituted the Gating DOE. Variations in gating were made on each casting based upon experience gained on the prior ones and also other input. Engineers not assigned to the program were invited to participate and several did. These castings were then examined with both X-ray and fluorescent penetrant, cut up and re-examined. The results indicated that the development process should proceed with the Process DOE. This will occur after the Design Review in October.

### **Casting Lots 15 & 16**

These two parts ran ahead of the process DOE in order to satisfy a need for hot fire testing. They were built up in wax to reflect the additional stock per the 96M66441 Rev. D blueprint. Lot 15 gating is basically the same as Lot 5, which was sound a part. Lot 16 gating benefitted from preliminary results on the Gating DOE castings. Both parts shipped in October 1993.

### **Casting Lots 5 & 7**

These castings were returned to us by Aerojet. Lot #5 required weld build, reheat treat and targeting and will be used to test liner installation. Lot 7 had enough stock, so did not require weld build, but was re-heat-treated and targeted. These parts ran as PCC P/N 93062, Lots 1 and 2 and shipped in August 1993. This work was outside the NASA contract, performed on Aerojet Purchase Orders.

## PROJECT STATUS

The process D.O.E. has been progressing smoothly. During the three month period all four lots completed their standard processing and have been cut-up. At the end of the quarter, the cut-up pieces were in queue be sent out for chem mill.

## PLAN FOR THE NEXT THREE MONTHS

- Complete metallography, and evaluation of D.O.E. lots.
- Begin preparing for P.D.R. with NASA.

## PART STATUS - DEVELOPMENT ENGINEERING

Page 26

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
2/9/94	<ul style="list-style-type: none"><li>Lot 17 - Gate removal complete - Post HIP NDT complete. Practice welding patches into window openings to complete 2/11/94, then to 2nd HIP.</li><li>Lot 20 - Will complete pre-HIP 100% NDT X-ray 2/14/94. Then to 1st HIP.</li><li>Lot 21 - Will cast 2/14/94.</li><li>Lot 22 - At Investing - will cast 2/28/94.</li></ul>
2/16/94	<ul style="list-style-type: none"><li>Lot 17 - Window patching practice complete. 2nd HIP complete. Post-HIP rework completing.</li><li>Lot 20 - Will complete pre-HIP NDT 2/18/94.</li><li>Lot 21 - Cast 2/16/94. Shell removal in-process.</li><li>Lot 22 - Will cast 2/28/94.</li></ul>
2/23/94	<ul style="list-style-type: none"><li>Lot 17 - Post-NDT mapping complete. Part marked for cut-up.</li><li>Lot 20 - Post-HIP NDT mapping complete. Completing post-HIP FPI rework, then to 100% X-ray.</li><li>Lot 21 - Shell removed. Gate removal completing. Going to NDT.</li><li>Lot 22 - Will cast 3/1/94.</li></ul>
3/25/94	<ul style="list-style-type: none"><li>Lot 17 - Part has been cut-up and has received post cut-up FPI.</li><li>Lot 20 - Part has been cut-up and is ready for post cut-up FPI.</li><li>Lot 21 - Part has been cut-up and is being de-burred.</li><li>Lot 22 - Homogenize is complete. Part is currently going through the solution heat treat prior to age.</li></ul>
4/1/94	<ul style="list-style-type: none"><li>Lot 17 - Part is in NDT for FPI mapping of the cut-up sections and should go to chem mill the week of 4/4.</li><li>Lot 20 - Part is in NDT for FPI mapping of the cut-up sections and should go to chem mill the week of 4/11.</li><li>Lot 21 - Part has been cut-up and de-burred and is in NDT queue.</li><li>Lot 22 - Part has been cut-up and de-burred and is in NDT queue.</li></ul>
4/8/94	<ul style="list-style-type: none"><li>Lot 17 - Part is out of NDT and is in queue to go to chem mill.</li><li>Lot 20 - Part is out of NDT and is in queue to go to chem mill.</li><li>Lot 21 - Part is in NDT and is almost finished being mapped.</li><li>Lot 22 - Part is in NDT on the FPI line.</li></ul>



## PART STATUS - DEVELOPMENT ENGINEERING

Page 27

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
-------------	---------------

4/29/94	<ul style="list-style-type: none"><li>• Lot 17 -</li><li>• Lot 20 - All lots are being sorted to select pieces to go to the lab prior to chem</li><li>• Lot 21 - mill. All lots will be sent to chem mill early next week.</li><li>• Lot 22 -</li></ul>
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2 March 1994

In reply to CDR-91-NASA-AMCC

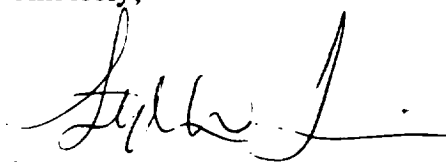
NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting  
Development (AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

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Sincerely,



Steve Irvine  
Program Manager  
Rocket Engineer & Space Component Development Engineering Program  
PRECISION CASTPARTS CORP.

SW/jld  
LSBO/6581  
NASA\quar.dec

cc: AP25B . . . . . 1 report & letter  
CN22D . . . . . 3 reports  
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NASA Scientific and Technical  
Information Facility . . . . . 2 reports  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090

2 March 1994

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 10

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

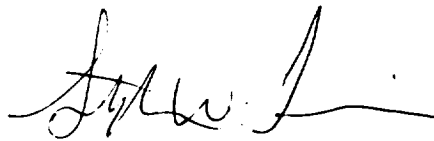
CDRL NO. 8

PREPARED BY

RICK SOLL  
Project Engineer



APPROVED BY



STEVE IRVINE  
Program Manager  
Rocket Engine & Space Component Development Engineering Team

PRECISION CASTPARTS CORP.  
Large Structural Business Operation  
4600 S.E. Harney Drive  
Portland, Oregon 97206

2 March 1994

CDR-91 NASA-AMCC

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main combustion Chamber (MCC).
- To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of eleven (11) castings.
- NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware. If the final castings are acceptable, they may be allocated to flight unit combustion chamber assemblies.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the twenty-eighth through thirtieth months of the contract, for the period November 1993 through January 1994.

## **WORK PERFORMED**

### **Casting Lots 9, 10, 12, 14**

These four parts constituted the Gating DOE. Variations in gating were made on each casting based upon experience gained on the prior ones and also other input. Engineers not assigned to the program were invited to participate and several did. These castings were then examined with both X-ray and fluorescent penetrant, cut up and re-examined. The results indicated that the development process should proceed with the Process DOE. This will occur after the Design Review in October.

### **Casting Lots 15 & 16**

These two parts ran ahead of the process DOE in order to satisfy a need for hot fire testing. They were built up in wax to reflect the additional stock per the 96M66441 Rev. D blueprint. Lot 15 gating is basically the same as Lot 5, which was sound a part. Lot 16 gating benefitted from preliminary results on the Gating DOE castings. Both parts shipped in October 1993.

### **Casting Lots 5 & 7**

These castings were returned to us by Aerojet. Lot #5 required weld build, reheat treat and targeting and will be used to test liner installation. Lot 7 had enough stock, so did not require weld build, but was re-heat-treated and targeted. These parts ran as PCC P/N 93062, Lots 1 and 2 and shipped in August 1993. This work was outside the NASA contract, performed on Aerojet Purchase Orders.

## PROJECT STATUS

We input lots 17, 18, 19, and 20 as process D.O.E. lots. Lot 19 was scrapped after dewax the week of 1/5/94 for dewax cracks in the manifold. Lot 21 was input to replace lot 19. Lot 18 was scrapped in the foundry due to a foundry practice error the week of 1/25/94. Lot 22 was input to replace lot 18. Gate tool design has been delayed until the completion of the process D.O.E.

## PLAN FOR THE NEXT THREE MONTHS

- Complete processing of the D.O.E. lots.
- Begin cut-up, metallography, and evaluation of D.O.E. lots.

## PART STATUS - DEVELOPMENT ENGINEERING

Page 25

Customer: NASA

PCC P/N: 20013

Customer P/N: 96M66441

Program: SSME

P.O. Nos: \_\_\_\_\_

Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
12/15/93	<ul style="list-style-type: none"><li>• Lot 17 - At Casting in Burn-out Furnace.</li><li>• Lot 18 - Investing.</li><li>• Lot 19 - Starting Investing.</li><li>• Lot 20 - Starting Gate Assembly.</li></ul>
12/22/93	<ul style="list-style-type: none"><li>• Lot 17 - Cast 12/19/93, currently at Burn-off.</li><li>• Lot 18 - Still Investing.</li><li>• Lot 19 - Had some repair, starting Investing.</li><li>• Lot 20 - Gating Assembly.</li></ul>
1/5/94	<ul style="list-style-type: none"><li>• Lot 17 - Completed thermal etch, then to FPI and NDT.</li><li>• Lot 18 - Investing complete. Will cast approximately 1/15/94.</li><li>• Lot 19 - Shell scrapped at Dewax. Non-repairable crack in manifold.</li><li>• Lot 20 - Completed Investing. Will cast approximately 1/22/94.</li><li>• Lot 21 - Will mold scrap replacement 1/15/94.</li></ul>
1/11/94	<ul style="list-style-type: none"><li>• Lot 17 - Have completed FPI and mapping. Currently undergoing NDT X-ray.</li><li>• Lot 18 - Will cast 1/17/94.</li><li>• Lot 20 - Will cast 1/17/94.</li><li>• Lot 21 - Molded. Doing pattern assembly. Should start gating week of 1/17/94.</li></ul>
1/18/94	<ul style="list-style-type: none"><li>• Lot 17 - NDTE X-ray complete. Will go to 1st HIP.</li><li>• Lot 18 - Will cast 1/22/94.</li><li>• Lot 20 - Will cast 1/22/94.</li><li>• Lot 21 - Pattern assembly. Investing.</li></ul>
1/25/94	<ul style="list-style-type: none"><li>• Lot 17 - Part HIPped. Gate removal started.</li><li>• Lot 18 - Scrapped at casting. Foundry practice error.</li><li>• Lot 20 - Cast successfully. Solution H.T. completed. Cap welding started.</li><li>• Lot 21 - Started Investing. To cast 2/8/94.</li></ul>





3 December 1993

In reply to CDR-91-NASA-AMCC

**Precision  
Castparts  
Corp.**

4600 S.E. Harney Drive  
Portland, Oregon 97206  
Telephone 503-777-3881  
Telex 36-0992  
Telecopier 503-652-3593

NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting  
Development (AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

We are transmitting data required by contract for your information and retention.

Sincerely,

John Bannister  
Program Manager  
Rocket Engineer & Space Component Development Engineering Program  
PRECISION CASTPARTS CORP.

SW/jld  
LSBO/6581  
NASA\quar.dec

cc: AP25B . . . . . 1 report & letter  
CN22D . . . . . 3 reports  
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COTR (Code EP62) . . 1 report & letter

NASA Scientific and Technical  
Information Facility . . . . . 2 reports  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090

3 December 1993

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 9

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

CDRL NO. 8

PREPARED BY



MATHEW PARDES  
Project Engineer

APPROVED BY



JOHN BANNISTER  
Program Manager

Rocket Engine & Space Component Development Engineering Team

PRECISION CASTPARTS CORP.  
Large Structural Business Operation  
4600 S.E. Harney Drive  
Portland, Oregon 97206

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main combustion Chamber (MCC).

To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of eleven (11) castings. NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware. If the final castings are acceptable, they may be allocated to flight unit combustion chamber assemblies.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the twenty-fifth through twenty-seventh months of the contract, for the period August 1993 through October 1993.

## WORK PERFORMED

### **Casting Lots 9, 10, 12, 14**

These four parts constituted the Gating DOE. Variations in gating were made on each casting based upon experience gained on the prior ones and also other input. Engineers not assigned to the program were invited to participate and several did. These castings were then examined with both X-ray and fluorescent penetrant, cut up and re-examined. The results indicated that the development process should proceed with the Process DOE. This will occur after the Design Review in October.

### **Casting Lots 15 & 16**

These two parts ran ahead of the process DOE in order to satisfy a need for hot fire testing. They were built up in wax to reflect the additional stock per the 96M66441 Rev. D blueprint. Lot 15 gating is basically the same as Lot 5, which was sound a part. Lot 16 gating benefitted from preliminary results on the Gating DOE castings. Both parts shipped in October 1993.

### **Casting Lots 5 & 7**

These castings were returned to us by Aerojet. Lot #5 required weld build, reheat treat and targeting and will be used to test liner installation. Lot 7 had enough stock, so did not require weld build, but was re-heat-treated and targeted. These parts ran as PCC P/N 93062, Lots 1 and 2 and shipped in August 1993. This work was outside the NASA contract, performed on Aerojet Purchase Orders.

## **PROJECT STATUS**

We have completed and evaluated the Gating D.O.E. and presented our findings at Design Review #2 on October 12. The project is progressing smoothly.

The tool rework and tool proving for Rev. D is complete. Gate tool design has not yet started due to the delay in completing the Gating DOE.

## **PLAN FOR THE NEXT THREE MONTHS**

- Start processing lots 17, 18, 19 and 20 as Process DOE.
- Design gate tooling.

## PART STATUS - R.E. & S.C. DEV. ENGINEERING

Page 23

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
7/28/93	<ul style="list-style-type: none"><li>• Lot 14 has completed Zygo. The Lab will be next.</li><li>• Lots 15 &amp; 16 still in Investing.</li><li>• Lot 5 has been welded. It will run FPI next and then be Hipped.</li><li>• Lot 7 requirements are still not set. We are now looking at additional X-Ray and Zygo since this part needs upgrading to Hot Fire status. We will quote it when the requirements are agreed upon.</li></ul>
8/4/93	<ul style="list-style-type: none"><li>• Lot 14 is ready to cut up for lab samples.</li><li>• Lots 15 &amp; 16 are scheduled to cast on 8/10.</li><li>• Lots 5 &amp; 7 should complete processing and ship by Friday.</li><li>• The PDR has been postponed from 8/17. The date is to be determined based on the availability of the lab work on the Gating DOE Castings.</li></ul>
8/11/93	<ul style="list-style-type: none"><li>• Lots 15 &amp; 16 successfully cast on 8/11 and are in shell removal. Planned ship date is 9/24.</li><li>• Lot 7 completed processing and shipped to Aerojet on 8/9 under P/N 93062, Lot #2.</li><li>• Lot 5 (weld build-up) will ship Friday, 8/13 to Aerojet. This is P/N 93062, Lot #1.</li><li>• Mod 10 to the contract has been received. It releases us to convert to Rev. D of the drawing and provides \$75,000 for tool rework.</li></ul>
8/18/93	<ul style="list-style-type: none"><li>• Lot 15 &amp; 16 through cleaning, thermal etch and cap weld.</li></ul>
8/25/93	<ul style="list-style-type: none"><li>• Lot 15 &amp; 16 through H.P. and gate removal, dim. inspection and starting FPI rework.</li></ul>
9/1/93	<ul style="list-style-type: none"><li>• Lot 15 &amp; 16 finished 1st FPI and started 100% X-ray.</li></ul>
9/8/93	<ul style="list-style-type: none"><li>• Lot 15 &amp; 16 completed 100% x-shoot and read and started X-ray rework.</li></ul>
9/15/93	<ul style="list-style-type: none"><li>• Lot 15 &amp; 16 completed X-ray rework and started patching manifold.</li><li>• Tool rework Rev. D completed. Tool proving starts.</li></ul>

## PART STATUS - R.E. & S.C. DEV. ENGINEERING

Page 24

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
9/22/93	<ul style="list-style-type: none"><li>• Lot 15 &amp; 16 continue patch welding.</li></ul>
9/29/93	<ul style="list-style-type: none"><li>• Lot 15 &amp; 16 continue patch welding.</li></ul>
10/6/93	<ul style="list-style-type: none"><li>• Lot 15 completed patch welding and had a second HIP and Post HIP homo and anneal.</li><li>• Lot 16 continues patch welding.</li></ul>
10/13/93	<ul style="list-style-type: none"><li>• Lot 15 passed final FPI, CMM and target.</li><li>• Lot 16 continues patch welding.</li></ul>
10/20/93	<ul style="list-style-type: none"><li>• Lot 15 shipped 10/15/93.</li><li>• Lot 16 completes patch welding.</li></ul>
10/30/93	<ul style="list-style-type: none"><li>• Lot 16 passed final FPI, CMM and target and shipped 10/30/93.</li><li>• Tool proving Rev. D complete.</li></ul>





17 August 1993

In reply to CDR-91-NASA-AMCC

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4600 S.E. Harney Drive  
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Sincerely,

Steve Weber  
Program Manager  
Rocket Engineer & Space Component Development Engineering Program  
PRECISION CASTPARTS CORP.

SW/jld  
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NASA\quar.aug

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NASA Scientific and Technical  
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800 Elkridge Landing Road  
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17 August 1993

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 8

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

CDRL NO. 8

PREPARED BY



G. L. HEMAN  
Project Engineer

APPROVED BY



S. L. WEBER  
Program Manager

Rocket Engine & Space Component Development Engineering Team

PRECISION CASTPARTS CORP.  
Large Structural Business Operation  
4600 S.E. Harney Drive  
Portland, Oregon 97206

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main combustion Chamber (MCC).
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- NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware. If the final castings are acceptable, they may be allocated to flight unit combustion chamber assemblies.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the twenty-second through twenty-fourth months of the contract, for the period May 1993 through July 1993.

## **WORK PERFORMED**

### **Casting Lots 9, 10, 12, 14**

These four parts constituted the Gating DOE. Variations in gating were made on each casting based upon experience gained on the prior ones and also other input. Engineers not assigned to the program were invited to participate and several did. These castings were then examined with both X-ray and fluorescent penetrant, cut up and re-examined. The results indicated that the development process should proceed with the Process DOE. This will occur after the Design Review in September.

### **Casting Lots 15 & 16**

These two parts are being run ahead of the process DOE in order to satisfy a need for hot fire testing. They were built up in wax to reflect the additional stock per the 96M66441 Rev. D blueprint. Lot 15 gating is basically the same as Lot 5, which was sound a part. Lot 16 gating benefitted from preliminary results on the Gating DOE castings. Both are expected to be good parts.

### **Casting Lots 5 & 7**

These castings have been returned to us by Aerojet. Lot #5 requires weld build, reheat treat and targeting and will be used to test liner installation. Lot 7 has enough stock, so does not require weld build, but will be reheat treated and targeted. These parts are running as PCC P/N 93062, Lots 1 and 2. Lot 1 has completed the weld build and is ready for HIP. This work is outside the NASA contract, being performed on Aerojet Purchase Orders.

## **PROJECT STATUS**

The loss of Lot 13 and the large amount of lab work required on the Gating DOE castings has set Design Review #2 back into September. However, the need to do tool rework prior to running the Process DOE would have extended the schedule anyway. This rework is not yet scheduled.

Gate Tool Design has not yet begun because of the delay in completing the Gating DOE.

The Contract Modification that is required in order to do the tool rework to Rev. D has not yet been received.

## **PLAN FOR THE NEXT THREE MONTHS**

- Complete evaluation on the Gating DOE.
- Schedule and complete Design Review #2.
- Process and complete Casting Lots 15 & 16 (Milestones 17 & 18).
- Do the tool rework to the Rev. D blueprint.
- Design gate tooling.

# PART STATUS - R.E. & S.C. DEV. ENGINEERING

Page 22

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

## DATE      STATUS

- 5/05/93
  - Lot #14 will cast Monday 5/10.
  - Lots 9 & 10 are ready for final Zyglo and lab work.
  - Lot 12 is at Chem Mill.
- 5/12/93
  - Lot #14 cast on Tuesday 5/11 and is in Shell Removal.
  - Lots 9 & 10 still require cut up.
  - Lot 12 is still at Chem Mill.
  - The Quarterly Report is in typing.
- 5/19/93
  - Lot #14 is at x-ray - almost complete.
  - Lots 9 & 10 are at NDT for final review.
  - Lot 12 is back from chem mill.
  - The Quarterly Report was sent out on Monday.
- 5/26/93
  - Lot 14 is complete with the X-ray Technique done.
  - Lots 9 & 10 are at Thermal Etch.
  - Lot 12 has completed NDT and may catch up to 9 & 10.
  - All of these parts (Lots 9, 10, 12 & 14) must complete lab work prior to the PDR.
- 6/2/93
  - Lots 9, 10, 12 are at NDT after thermal etch.
  - NASA has requested span times for the next 2 Hot Fire parts to be delivered to Aerojet. We have quoted 16 weeks without tool rework and 19 weeks with tool rework. The waxes would be hand modified to meet the 16 weeks. Jay Dennis will get back to us this week on how they want to go.
- 6/9/93
  - Lots 9, 10, & 12 are almost complete at NDT and will be cut for the lab work.
  - Lot #14 is being deburred and will HIP next.
  - We are inputting the next 2 Hot Fire parts. We will have waxes on Monday, 6/14. The configuration will be modified in wax. Tool rework will then be done after the contract mod is received.
- 6/23/93
  - Lot 14 is being deburred and will HIP next. Final FPI before Chem Mill.
  - Lot 14 will be completed by July 31.
  - Lots 15 & 16 due out of assembly - Lot 15, 7-2-93;  
Lot 16, 7-8-93.

Customer: NASA PCC P/N: 20013Customer P/N: 96M66441 Program: SSMEP.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber**DATE            STATUS**

- 7/7/93
- Lot 14 has been used for technique studies in X-Ray. It is ready for Chem Mill.
  - Lot 15 is in gate assembly and will be gated the same as No. 5, which is good. The wax build up will be completed after the gating is done.
  - Lot 16 is in pattern assembly.
  - PCC is awaiting a Purchase Order or Contract Mod for tool rework.
- 7/14/93
- Lot 14 is on its way to Chem Mill.
  - Lot 15 is ready for Investing.
  - Lot 16 is in Gating Assembly.
  - Lot 5 is back from Aerojet for weld build-up. Our goal is to complete it in 4 weeks. It is running as P/N 93062.
- 7/21/93
- Lot 14 is at Chem Mill. It will be back on Monday.
  - Lots 15 & 16 are in Investing. Tentative cast date is 8/2.
  - Lot 5 will start welding today.
- 7/28/93
- Lot 14 has completed Zyglo. The Lab will be next.
  - Lots 15 & 16 still in Investing.
  - Lot 5 has been welded. It will run FPI next and then be Hipped.
  - Lot 7 requirements are still not set. We are now looking at additional X-Ray and Zyglo since this part needs upgrading to Hot Fire status. We will quote it when the requirements are agreed upon.





**Precision  
Castparts  
Corp.**

4600 S.E. Harney Drive  
Portland, Oregon 97206  
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Telex 36-0992  
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12 May 1993

In reply refer to CDR-91-NASA-AMCC

NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting  
Development (AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

We are transmitting data required by contract for your information and retention.

Sincerely,

  
Steve Weber

Program Manager  
Rocket Engine & Space Component Development Engineering Program  
Precision Castparts Corp.

SW/jld  
LSBO/7354

cc: AP25-B . . . . . 1 report & letter  
CN22D . . . . . 3 reports  
AT01 . . . . . 1 report  
EM15 . . . . . 1 report  
COTR (Code EP62) . . . . . 1 report & letter

NASA Scientific and Technical  
Information Facility . . . . . 2 reports  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090

12 May 1993

CDR-91-NASA-AMCC

**QUARTERLY STATUS REPORT**

**NUMBER 7**

**ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM**

**CONTRACT NAS8-39027**

**CDRL NO. 8**

**PREPARED BY**



**G. L. HEMAN  
Project Engineer**

**APPROVED BY**



**S. L. WEBER  
Program Manager**

**Rocket Engine & Space Component Development Engineering Team**

**PRECISION CASTPARTS CORP.  
Large Structural Business Operation  
4600 S.E. Harney Drive  
Portland, Oregon 97206**

QUARTERLY STATUS REPORT

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## **QUARTERLY STATUS REPORT**

### **INTRODUCTION**

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main combustion Chamber (MCC).
- To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of eleven (11) castings.
- NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the nineteenth through twenty-first months of the contract, for the period February 1993 through April 1993.

## **WORK PERFORMED**

### **Casting Lot #6**

This casting was cut up and examined as an Engineering Mockup after it was determined to not be suitable as a shippable casting. The information was used as part of the Gating DOE.

### **Casting Lot #9**

This is the first Gating DOE part. It processed through Non-Destructive Testing, was cut-up and chem-milled. It was invoiced as Contract Milestone #13.

### **Casting Lot #10**

This is the second Gating DOE casting. It processed the same as Lot #9 and was invoiced as Milestone #14.

### **Casting Lot #12**

This is the fourth Gating DOE part. It has processed through Non-Destructive Testing, been cut-up and chem-milled. Final lab work will follow. It was invoiced as Milestone #16.

### **Casting Lot #13**

This lot replaced Lot #11 as the third Gating DOE part. It too separated during the Investing Cycle and was scrapped. The problem was analyzed to be because of a large ring gate on the bottom of the mold that was overstressing the assembly during dipping.

### **Casting Lot #14**

This lot replaced Lot #13 as the third Gating DOE part. The overstressing problem was solved by fabricating the large bottom ring gate hollow instead of solid as is usually done. Special venting was required during the dewax operation. This approach was successful.

However, a dewax crack did appear in the forward manifold portion of the mold. This was patch dipped successfully. The cooling air that was to be passed through the manifold after casting will only be effective for 1/2 of the circumference. This will be taken into account during the Engineering Evaluation.

## **PROJECT STATUS**

The loss of Lots 11 and 13 have slowed the progress of the program. Lot #14 will process in May and complete lab evaluation in June. Evaluation of the Gating DOE will follow. This will put the second PDR into late June or early July.

PCC has received a copy of Drawing #96M66441 Rev. D. This drawing reflects changes in part configuration that will be required by NASA prior to manufacture of the next two castings in the program. Tool rework will be required. This is currently being evaluated for its effect on the schedule.

## **PLAN FOR THE NEXT THREE MONTHS**

- Complete and invoice casting Lot #14 (Milestone #15).
- Evaluate the Gating DOE and determine the gating for the next two deliverable castings. Design gate tooling.
- Quote the required rework to incorporate the Rev. D blueprint.
- Do the rework after release by NASA.
- Start to process castings for Milestones 17 & 18.
- Schedule and complete PDR #2.

# PART STATUS - R.E. & S.C. DEV. ENGINEERING

Page 19

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
2/4/93	<ul style="list-style-type: none"><li>• Lot 6 is at NDTE.</li><li>• Lot 9 had NDTE FPI yesterday. It is now at CMM prior to X-ray.</li><li>• Lot 10 is at NDTE FPI. CMM is done. X-ray is next.</li><li>• Lot 12 will CMM with lot 9 and then go to FPI.</li><li>• Lot 13 is in gate assembly.</li></ul>
2/20/93	<ul style="list-style-type: none"><li>• Lot 6 NDT complete after cut up. Chem Mill, Thermal Etch, FPI and lab work to follow.</li><li>• Lot 9, 10, and 12 are ion x-ray after FPI. Cut up will follow.</li><li>• Lot 13 broke at a riser at 4th dip in Investing. Howcroft is evaluating.</li></ul>
2/17/93	<ul style="list-style-type: none"><li>• Lot 6 at Sandblast and will then go to Chem Mill.</li><li>• Lot 9 completed X-ray. Being evaluated.</li><li>• Lot 10 completed X-ray. Showed one place of shrink in the jacket. The leakage in the Aft Manifold caused no problem with the DOE.</li><li>• Lot 12 in X-ray.</li><li>• Lot 13 is being repaired in Assembly and will then continue dipping.</li><li>• Frank Sciorelli of Aerojet called for dimensional information. John Davis will follow up.</li></ul>
2/24/93	<ul style="list-style-type: none"><li>• Lot 6 will go to Chem Mill today.</li><li>• Lots 9 &amp; 10 are cut and will be invoiced this month.</li><li>• Lot 12 has completed NDT. It will be cut after Jim's review.</li><li>• Lot 13 is repaired and ready to continue dipping. It will be evaluated at dewax.</li></ul>
3/3/93	<ul style="list-style-type: none"><li>• Lot 6 is at Chem Mill</li><li>• Lots 9 &amp; 10 are cut and are deburring.</li><li>• Lot 12 is ready for cutting but may be used first to complete the x-ray technique.</li><li>• Lot 13 separated again in dipping and is scrap.</li><li>• Lot 14 is ordered to replace lot 13.</li><li>• Jim will evaluate the loss of #13's impact on the Gating DOE. This will affect the timing of the next PDR tentatively set for April or May</li></ul>

# PART STATUS - R.E. & S.C. DEV. ENGINEERING

Page 20

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
3/10/93	<ul style="list-style-type: none"><li>• Lot 6 still at Chem Mill.</li><li>• Lots 9 &amp; 10 at NDT, ready for HIP.</li><li>• Lot 12 will be used to complete x-ray tech next week and then will be cut.</li><li>• Lot 14 molding complete and components are in Wax Inspection.</li><li>• Lot 14 will be run with the same gating as lot 13 with some things to lighten the load in Investing.</li><li>• We are expecting dimensional changes to accommodate the platelet liner versus the original VPS liner. These will be evaluated when received.</li></ul>
3/17/93	<ul style="list-style-type: none"><li>• Lot 6 is at NDT for final FPI after Chem Mill.</li><li>• Lots 9 &amp; 10 are ready for HIP.</li><li>• Lot 12 - X-ray tech will be completed Thursday and then will be cut. We will invoice it this month.</li><li>• Lot 14 Pattern is almost complete and will go to CMM.</li><li>• A Rev "D" blueprint will come which will describe the changes required by Aerojet. NASA wants these incorporated for the next two castings.</li><li>• Davis and Howcroft will come up with a rework plan for the windows and patches.</li></ul>
3/24/93	<ul style="list-style-type: none"><li>• Lot 6 ready for the lab.</li><li>• Lots 9 &amp; 10 will HIP today.</li><li>• Lot 12 x-ray tech is not quite complete.</li><li>• Lot 14 is in Gate Assembly.</li><li>• The window and patch rework plan will be complete tomorrow.</li><li>• Jim working with SSBO to get them to run the patches.</li></ul>
3/31/93	<ul style="list-style-type: none"><li>• The lab work is progressing.</li><li>• Lots 9 &amp; 10 are ready for Chem Mill.</li><li>• A problem exists with a portion of the x-ray technique. Jim and Bruce to work with the x-ray department to resolve it.</li><li>• Lot 14 is ready for Framing.</li><li>• The window and patch rework plan will be ready for quoting on 4/5.</li><li>• Terry Cuddeford at SSBO has agreed to run the patch tool. Bruce will work out the quality plan details.</li><li>• The Rev. D blueprint still has not been received. No problems are anticipated. Tool rework will be required.</li></ul>



# PART STATUS - R.E. & S.C. DEV. ENGINEERING

Page 21

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
4/07/93	<ul style="list-style-type: none"><li>• Lot #14 is in Investing.</li><li>• Lots 9 &amp; 10 are cut up and at outside Chem Mill.</li><li>• The new Rev. D blueprint is expected today.</li></ul>
4/14/93	<ul style="list-style-type: none"><li>• Lab work on #6 is progressing.</li><li>• Lot #14 is having the manifold installed after 11th dip.</li><li>• Lots 9 and 10 are still at Chem Mill.</li><li>• The Rev. D blueprint is being marked up by John Davis to determine the changes. There is apparently more involved than a simple wall thickness change. All three tools will require rework. All of our fixtures will probably also require rework. This could affect the delivery of the next two hot fire castings.</li></ul>
4/21/93	<ul style="list-style-type: none"><li>• Lot #6 lab work is complete.</li><li>• Lot #14 finished Investing and will dewax tonight. It should cast next week.</li><li>• Lots 9 &amp; 10 are at Chem Mill.</li><li>• Lot 12 is ready for Chem Mill.</li><li>• The Rev D blueprint is being routed on a report of change for evaluation. Tooling quotes are in-process. The part weight increase is 34 pounds.</li></ul>
4/28/93	<ul style="list-style-type: none"><li>• Lot #6 is complete.</li><li>• Lot #14-The forward manifold cracked at dewax. It will be patched and poured, but 1/2 of the manifold will be plugged. This will be taken into account during the DOE evaluation. The repair and casting will require two weeks.</li><li>• Lots 9 and 10 are back from Chem Mill and are being evaluated for grain size.</li><li>• Lot 12 is going to Chem Mill.</li></ul>

12 Feb. 1993

CDR-91-NASA-AMCC

**QUARTERLY STATUS REPORT**

**NUMBER 6**

**ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM**

**CONTRACT NAS8-39027**

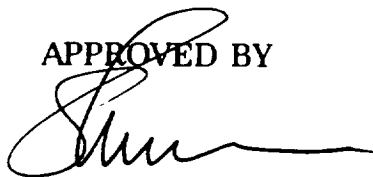
**CDRL NO. 8**

**PREPARED BY**



**G.L. HEMAN**  
Project Engineer

**APPROVED BY**



**S.L. WEBER**  
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12 Feb. 1993

CDR-91 NASA-AMCC

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main Combustion Chamber (MCC).
- To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of eleven (11) castings.
- NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the sixteenth through eighteenth months of the contract, for the period of November 1992 through January 1993.

## WORK PERFORMED

### **Casting Lot #3**

The cut up pieces were shipped to NASA on 11/19/93.

### **Casting Lot #5**

This casting completed processing and shipped to Aerojet on 11/19/92. It showed some areas of shrink in the Aft Manifold inner wall but was successfully repaired.

### **Casting Lot #6**

This casting had shrink which did not HIP out. Attempts to repair it after HIP produced outgassing. It was eventually replaced by Lot #7 for shipping to Aerojet. Lot #6 has been cut up as an Engineering Sample. The knowledge gained will be used in the Gating DOE. This part was invoiced in November of 1992.

### **Casting Lot #7**

This casting showed a much higher quality level at NDTE than did Lot #6. So, even though it was behind lot #6 in processing, the decision was made for it to become the shippable casting. It completed processing and shipped on 12/19/93.

### **Casting Lot #8**

This lot was scrapped after Assembly as it was no longer needed in the program.

### **Casting Lot #9**

This is the first Gating DOE part. It cast on 1/21/93 with lots 10 & 12. It has completed shell removal and looks good visually.

**Casting Lot #10**

This is the second Gating DOE part. It shows core failure in the Aft Manifold. A full evaluation will take place at NDTE. It is not yet known if this will affect the Gating DOE.

**Casting Lot #11**

This assembly cracked in a pattern seam during dipping and was scrapped. It was replaced with Lot #13.

**Casting Lot #12**

This is the third Gating DOE part. It is in gate removal and looks good visually.

**Casting Lot #13**

This is the fourth (and last) Gating DOE part. Because it replaced Lot #11, it is behind the other three. It is, however, expected that the Engineering Evaluation will be completed at PCC by March 31. The pattern is assembled and being checked at CMM.

**Production X-Ray Techniques**

A technique acceptable to PCC is being used on current castings.

**Window Welding**

Welding techniques that give acceptable results have been developed. One technician and one production welder are currently qualified to them.

## PROJECT STATUS

The program is going well even with the two week plant shutdown in December and losing Lot #11 in Investing. We still plan to complete the Gating DOE by the end of March.

It appears that more money needs to be allocated by NASA in order to pay for the next four castings. The current amount allotted is \$1,351,000 and ~~\$2,268,841~~ will be needed by 3/31/93.

~~\$2,268,841~~  
\$2,341,424

## PLAN FOR THE NEXT THREE MONTHS

- Complete and invoice castings-Lots #9, #10, #12, and #13. (Milestones 13 through 16)
- Prepare for PDR #2 in late April or May.
- Start designing gate tooling (to be invoiced after 10/1/93).
- Complete the window welding technique and train production welders.

# PART STATUS--R.E. & S.C.D. ENGINEERING

Page: 16

Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
-------------	---------------

- |         |   |
|---------|---|
| 11/4/92 | <ul style="list-style-type: none"><li>• Lot 5-window welding is complete and the casting is at HIP.</li><li>• Lot 6-Some areas needed repair after HIP. Some outgassing has resulted.</li><li>• Lot 7-Cast on 10/28. Preliminary X-ray shows two small areas of shrink in the jacket. The manifolds will be X-rayed next. This part may become the shipper if its quality is better than Lot 6.</li><li>• Lot 8-still on hold.</li><li>• Lot 9- will frame today and start investing tomorrow.</li><li>• Lot 10-pattern is complete and going to CMM.</li><li>• Lot 11-in wax cleaning.</li><li>• Lot 12-in molding</li><li>• The Quarterly Report has been sent.</li></ul> |
|---------|---|



# PART STATUS--R.E. & S.C.D. ENGINEERING

Page: 17

Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

DATE STATUS

- 11/11/92
- Lot #5 is at NDT. X-ray film on two welds will be examined to determine if another HIP is required.
  - Lot #6 is being x-rayed for three ground areas in the jacket. Manifolds are ok.
  - Lot #7 manifolds are being x-rayed.
  - Lot #9 is in Investing.
  - Lot #10 is ready for framing.
  - Lot #11 pattern assembly is complete.
  - Lot #12 is in Wax Cleaning.
- 11/18/92
- Lot #5- Processing is completed. It will ship this week to Aerojet. Davis will check with Wendell Burkhardt at Aerojet to see what dimensional information is required.
  - Lots #6 & #7-Evaluation of lot #7 at NDTE shows a better quality part than lot #6. Lot #7 will be processed to ship. Lot #6 will be cut up for engineering evaluation. Lot #7 is in the Zygo salvage cycle. Patch welding should start this week. Lot #6 will be invoiced this month.
  - Lot #9-In Investing. The air manifolds are installed.
  - Lot #10-In Investing. First-dipped yesterday.
  - Lot #11-The pattern was damaged but has been repaired to engineering's satisfaction. Gate assembly is started.
  - Lot #12 is ready for Pattern Assembly.
- 11/25/92
- Lot #3-Pieces shipped to MSFC 11/19/92.
  - Lot #5-Shipped to Aerojet 11/19/92.
  - Lot #6-Cut up at NDTE.
  - Lot #7-In Welding
  - Lot #9-has been dewaxed.
  - Lot #10-In dipping. The air manifold will be installed today.
  - Lot #11-In Framing today.
  - Lot #12-In Gating Assembly.
- 12/2/92
- Lot 6-At NDTE
  - Lot 7-At NDTE prior to patch weld.
  - Lot 9-Cast next week
  - Lot 10-Close to dewax, may cast next week.
  - Lot 11-Still in Assembly because it required rework on the gating.
  - Lot 12-Will 1st dip today.

# PART STATUS—R.E. & S.C.D. ENGINEERING

Page: 18

Customer: NASA

PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_

Description: Main Combustion Chamber

DATE	STATUS
------	--------

- |          |   |
|----------|---|
| 12/9/92  | <ul style="list-style-type: none"><li>• Lot 6—Complete after 1st of year.</li><li>• Lot 7—Completing patch weld tomorrow to go to HIP on schedule, to ship next week.</li><li>• Lots 9 &amp; 10—Cast date not definite. Meeting being scheduled.</li><li>• Lot 11—IBL</li><li>• Lot 12—At manifold installation.</li></ul>  |
| 12/16/92 | <ul style="list-style-type: none"><li>• Lot 6—Engineering evaluation to be completed in January.</li><li>• Lot 7—Should ship this week.</li><li>• Lots 9 &amp; 10—These two will probanly cast together the first week in January (afer shutdown).</li><li>• Lot 11—Lost in Investing because of bad pattern seal. This will be replaced by Lot #13.</li><li>• Lot 12—In Investing</li><li>• Lot 13—Molding this week</li><li>• The intent is to have evaluations completed and invoiced on Lots 9, 10, 11, &amp; 13 in March of 1993.</li><li>• Tentative date for the next PDR is April 1993.</li></ul> |
| 1/6/93   | <ul style="list-style-type: none"><li>• Lot 6—At NDTE for cut up.</li><li>• Lot 7—Shipped 12/19/93.</li><li>• Lots 9 &amp; 10—Cast date not set. Probably next week.</li><li>• Lot 12—May cast with 9 &amp; 10.</li><li>• Lot 13—Molded.</li></ul>  |
| 1/13/93  | <ul style="list-style-type: none"><li>• Lot 6 at NDT for cut up – Jim working.</li><li>• Lots 9, 10 &amp; 12 will cast sequentially on 1/18 or 1/19.</li><li>• Lot 13 has been molded.</li></ul>  |
| 1/21/93  | <ul style="list-style-type: none"><li>• Lot 6 still at NDT for cut up.</li><li>• Lots 9, 10, &amp; 12 will cast 1/21 &amp; 1/22.</li><li>• Lot 13 is in Pattern Assembly.</li></ul>   |
| 1/27/93  | <ul style="list-style-type: none"><li>• Lot 13 is at CMM for Wax Dimension</li><li>• Lot 9 is at First Inspection.</li><li>• Lot 10 has core failure in the aft manifold.</li><li>• Lot 12 is in gate removal.</li><li>• Lot 6 is being evaluated at NDT.</li></ul>   |

03 November 1992

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 5

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

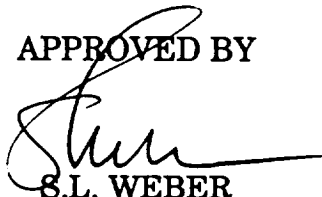
CDRL NO. 8

PREPARED BY



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03 November 1992

CDR-91 NASA-AMCC

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- \* To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main Combustion Chamber (MCC).
- \* To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of eleven (11) castings.
- \* NASA will use these eleven (11) castings as engineering and process development units or as development prototype ground-test hardware.

NOTE: The quantities listed above reflect those in contract modification #7.

This report describes the status of the program and the work performed during the thirteenth through fifteenth months of the contract, for the period of August 1992 through October 1992.

## **WORK PERFORMED**

### **Casting Lot #3**

Engineering Evaluation was completed by PCC and presented at the PDR at MSFC in August. Milestone #6 was invoiced.

### **Casting Lot #4**

PCC Lot #4, the first deliverable to Aerojet, cast on August 12. It was fully processed including all window welding, and shipped on September 30. It was invoiced as Milestone #7.

### **Casting Lot #5**

This casting is being processed as the second deliverable to Aerojet. It has been HIPped and repaired. The window welding is almost complete. It is targeted to ship the week of November 9.

### **Casting Lot #6**

This casting is being processed as the third deliverable to Aerojet. It has been HIPped and is being reviewed at NDT. It appears to be of lesser quality than Lots #4 and #5 and may be switched with Lot #7, depending upon its quality.

### **Casting Lot #7**

This casting ran into scheduling problems in the MasterCaster furnace. It cast on October 29, eight days behind schedule. It is currently in shell and gate removal. It will either ship in place of Lot #6 or be a PCC Engineering Sample, depending upon part quality.

### **Casting Lot #8**

This part is not needed under the current requirements. it is a fully-gated wax assembly, but it is being held prior to the Investing operation, in anticipation of scrapping it. This will be at no charge to NASA.

**Casting Lots #9, #10, #11, #12**

These will be the Gating DOE parts and are in Wax Cleaning and Wax Assembly.

**Fixtures**

The additional process fixturing that is required for the Gating and Process DOE castings has been purchased. It was invoiced as Milestone #2.

**PRELIMINARY DESIGN REVIEW (PDR-1)**

Wednesday, August 26, 1992, PCC's Product Development Team presented our findings from work completed through casting Lot #3 to the NASA team.

After an introduction by Steve Weber, PCC team members John Davis, Jeff Miller, Bruce Haphey, and Jim Howcroft covered the various aspects of PCC's casting development work to-date.

Following review of lessons learned to-date, Jim Howcroft presented PCC's initial plan for the 4-part Gating Design Of Experiment (DOE). Jim noted this design was preliminary in nature and subject to change based on review of Lot #4, which would be completed too late for inclusion in PDR-1. We also noted that Lots #5 and #6 were in process and might also influence our thinking as results became available.

Over all, PCC felt progress to-date exceeded our original expectations. However, some critical issues remained. Based on input received at this review and later by phone, Lots #7, #8, and #9 were (until mid-October) scheduled for completion prior to running lots #10, #11, #12, and #13 for the gating DOE. Subsequent changes required by NASA resulted in Lot #8 being scrapped in wax and Lot #9 being moved into Gating DOE #1.

Input received from NASA participants was favorable and constructive in nature which should help us tailor our presentation at PDR-2 (following our Gating DOE) to better conform to our customer's requirements.

**Contract Modification #7**

Review of this modification showed two castings still to be shipped in the second quarter of calendar year (CY) 1993. These need to be changed to the fourth quarter. Also, Milestone #3, Gate Tooling, will be billed by PCC October 1993 or later.

**Pressure Testing**

A local vendor, Westcon Inc., is able to hydraulic pressure test to 7500 psi the manifolds on this casting. After an initial inquiry by NASA, it was determined that Aerojet would do the testing.

**PROJECT STATUS**

The program is going well with the exception that Lot #5 is behind schedule. Lots #6 and #7 should be complete by the 12/31 delivery date shown in Contract Mod #7.

The decision has been made at PCC to close down all three structural division plants, including LSBO, from the end of the work day, December 18 until January 4, 1993. The full effect of that closure on this program is not yet known.

**PLAN FOR THE NEXT THREE MONTHS**

- Complete and invoice castings-Lots #5, #6, & #7. (Milestones 8, 9, & 10)
- Process and partially evaluate gating DOE castings-Lots #9, #10, #11, #12.
- Complete the production X-Ray technique and submit it for NASA approval.
- Complete the window welding technique and train production welders.



# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

DATE STATUS

8/5/92

- Lot #5 Pattern has been assembled and will go to CMM.
- Lot #4 will dewax 8/6. The pour date is probably Monday 8/10.
- Lot #3 micros went to an outside lab. They are due back on 8/10.

8/12/92

- Lot #4 will pour today.
- Lot #5 is in Investing.
- PDR work is progressing for presentation the week of 8/24 at NASA.
- Contract mod #6 was received. It switches two castings from the end of the program to the current time for delivery in November. These will be PCC Lot numbers 6 & 7, best effort, windows welded, and targeted.
- Lot #3 was billed last week. It was listed as Milestone #6 per contract Mod #5. Lot #2, billed in March was listed as Milestone #6 at that time was actually Milestone #5.

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
-------------	---------------

- |         |   |
|---------|---|
| 8/25/92 | <ul style="list-style-type: none"><li>• Lot #4 is ready for NDTE. Window welding will follow.</li><li>• A new requirement to do a high pressure test prior to shipment is being considered. A local vendor has been found and has been requested to quote. The manifolds on Lot #4 showed some dirt which will be easily repairable. Also, a local area of shrink on the inside wall of the Aft Manifold has been found. It does not show in X-Ray so the extent is not known. Its depth is currently about 3/8". We will grind it to 1/2" max. If it is not clean, we will bake the part to remove any residual penetrant and weld it. The weld will be inspected to assure its soundness and the casting will then be HIPped after the windows are welded shut.</li><li>• Lot #5 will dewax tonight. Tentative cast date is 8/24.</li><li>• Lot #6 has been molded.</li><li>• Contract Mod #6 acknowledgement will be delivered at the PDR on 8/26 by Jon Down.</li></ul> |
| 9/2/92  | <ul style="list-style-type: none"><li>• PDR #1 was completed on August 27th. It went smoothly and was well received by NASA.</li><li>• Lot #4 is in window welding. It is going slowly because of the welding-inspection cycles, but the quality is good and no major problems. It should complete this week.</li><li>• Lot #5 is pouring today.</li><li>• Lot #6 is in Wax Molding.</li><li>• Patch tooling will be reworked to change thickness and to add gate stubs. This will improve the consistency in the patch welding process.</li><li>• The four Gating DOE castings (PCC Lot #s 10, 11, 12, 13) will be scheduled right behind the two hot fire parts.</li></ul>  |

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
9/9/92	<ul style="list-style-type: none"><li>• Lot #4 windows are welded, the casting got HIPped over the weekend and will be vacuum heat treated tonight. NDT and Age Heat Treat still follow.</li><li>• Lot #5 will be cap welded and go to NDTE next.</li><li>• Lot #6 is in Investing.</li><li>• Lot #7 is in Wax Cleaning.</li></ul>
9/16/92	<ul style="list-style-type: none"><li>• Lot #4 at NDTE. Target date week of 9/21.</li><li>• Lot #5 at NDTE for FPI report and then defect repair. X-Ray will follow. Window welding will begin 9/21.</li><li>• Lot #6 due to cast 9/23. Casting fixture being updated. Burnout to start 9/19.</li><li>• Lot #7 is assembled. Will go to CMM 9/17. Gating to be completed by 9/26/92.</li><li>• Window closure tooling to be sent out for rework to add gate stubs. Patches to be manufactured at SSBO and supplied for LSBO installation. Work to be completed to allow use on gating DOE castings by production welding personnel.</li><li>• Inlets awaiting final drawing prior to final quote.</li><li>• Pressure testing will not be available on lots #4 or #5.</li></ul>
9/23/92	<ul style="list-style-type: none"><li>• Lot #4 is scheduled to complete processing on Friday, 9/25.</li><li>• Lot #5 is at preliminary X-ray. It will then start window patching.</li><li>• Lot #6 cast on Thursday, 9/24.</li><li>• Lot #7 Pattern Assembly is complete. Gate assembly will follow.</li><li>• Lot #8 is through Wax Cleaning ready for Pattern Assembly.</li><li>• Lot #9 has completed Molding.</li></ul>

(continued on next page)

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

DATE STATUS

9/23/92 (continued from previous page)

- Lots 8 & 9 will be the hot fire parts.
- Lots 10, 11, 12, 13--These will be the Gating DOE parts. They are being scheduled to run at one per week.
- It appears that there will be no requirement for PCC to pressure test this part.

9/30/92

- Lot #4 will be shipped today.
- Lot #5 is at X-ray. This casting will be used to establish the production X-ray technique.
- Lot #6 is at First Dimension. This casting shows caustic bleeds in the jacket ribs. This would indicate surface shrink in four areas. This will be fully evaluated at NDTE. This casting had a cooling passage in the aft manifold as well as the ribs.
- Lot #7 is in Investing. This casting will have cooling passages in both manifolds as well as the ribs.
- Lot #8 is in Gating Assembly.
- Lot #9 is awaiting pattern assembly.
- Lots 10-13 have been scheduled. Lot 10 will mold by 10/16. The rest will follow at one per week.

10/7/92

- Lot #5 exhibits some shrink in the aft manifold inner wall. This will be further evaluated.
- The production x-ray technique development is going slowly. Lot #5 will be evaluated and moved on. The technique will be developed on subsequent castings.
- Lot #6 has been cap welded and will go to NDT next.
- Lot #7 should complete Investing today. It should cast next week.
- Lot #8 is ready for framing.
- Lot #9 is awaiting pattern assembly.

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
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10/14/92

- NASA's program has changed, but the total effect on PCC is not yet known. Lot #8 probably will not be needed and is on hold prior to Investing. Lot #9 will be the first of the Gating DOE parts, which will now be Lots 9 through 12. Lots 13 and on are on hold prior to molding until further notice. Lot #7 will cast next week with air cooling on the jacket and in both manifolds. Regulators are being installed on the air lines to accommodate this. Lots 5 & 6 will probably go through a preliminary HIP prior to window welding in order to improve their quality.
- Further conversations are going on with NASA in order to confirm their real needs.

10/21/92

- Contract Mod. #7 has been received from NASA and is being reviewed.
- Lots 5 & 6 are being processed.
- Lot 7 is being delayed in casting because of production schedules.
- Lot 8 has been cancelled.
- Lot 9 is ready for gating assembly as the #1 gating DOE part.
- Lot 10 has been molded.

10/28/92

- Contract Mod #7 needs some changes. These were discussed with Jay Dennis.
- Lot 5 has been HIPped and repaired. The window welding is almost complete.
- Lot 6 is being reviewed after HIP.
- Lot 7 still has not cast.
- Lot 9 is being gated.
- Lot 10 is in Pattern Assembly.
- Lot 11 is in Wax Cleaning.

August 11, 1992

In reply refer to CDR-91-NASA-AMCC

NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting  
Development (AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

We are transmitting data required by contract for your  
information and retention.

Sincerely,

Steve Weber

Program Manager  
Rocket Engine & Space Component Development Engineering  
Program  
Precision Castparts Corp.

cc:	AP25-B_____	1 report & letter
	CN22D_____	3 reports
	AT01 _____	1 report
	EM15 _____	1 report
	COTR (Code EP62)_____	1 report & letter

NASA Scientific and Technical  
Information Facility\_\_\_\_\_ 2 reports  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090

11 August 1992

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 4

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

CDRL NO. 8

PREPARED BY

G.L. HEMAN  
Project Engineer



APPROVED BY



S.L. WEBER  
Program Manager

Rocket Engine & Space Component Development Engineering Team

PRECISION CASTPARTS CORP.  
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11 August 1992

CDR-91 NASA-AMCC

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QUARTERLY STATUS REPORT

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## **QUARTERLY STATUS REPORT**

### **INTRODUCTION**

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- \* To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main Combustion Chamber (MCC).
- \* To accomplish this by manufacture of twenty-four (24) developmental castings of which delivery to the government will consist of a minimum of twelve (12) castings.
- \* NASA will use these twelve (12) castings as engineering and process development units or as development prototype ground-test hardware.

NOTE: The quantities listed above reflect those in contract modification #6.

This report describes the status of the program and the work performed during the tenth through twelfth months of the contract, for the period of May 1992 through July 1992.

## **WORK PERFORMED**

### **Casting Lot #3**

This is the second engineering gating sample in the development program. Information learned from Lot #1 (Engineering Sample #1) and Lot #2 (the first "best effort" deliverable) was used in gating this casting.

Six ribs were affected by local cooling which took place after casting, outside the furnace. The intent is to better cool the area between the ribs which exhibited surface porosity in Lot #2.

The part cast on June 7. The position of the mold caused metal spillage over the outside. The mold filled completely, however. Casting techniques will be modified to correct this problem on future pours. NDT examination of the casting showed some areas of shrink. The local cooling portion appeared to be clean. Later examination after Chem Mill showed shrink on the lower manifold which may be attributable to the metal spillage at casting.

Lot #3 continued to process. The windows were patched and a welding technique established which will be refined on later castings. Some distortion was present which should be preventable on future parts. The casting has been cut up and is awaiting final examination of micros.

### **Casting Lot #4**

Lot #4 was molded and invested. This casting is intended for delivery by October 1.

### **Casting Lot #5**

Lot #5 was molded and the pattern was assembled and sent to CMM for dimensional inspection. Target delivery date is Oct. 1 but is in doubt because of a late start.

***(WORK PERFORMED CONTINUED)***

**Fixtures**

Additional fixturing to handle the parts for delivery in October, November, and December are being quoted and procured.

**PDR**

Gathering of data for PDR #1 at Huntsville on 8/26 & 8/27 has begun.

**PROJECT STATUS**

The program is going well with the exception of delivery on Lot #5. The October 1 date is in jeopardy with October 15th being more realistic.

**PLAN FOR THE NEXT THREE MONTHS**

- Bill for Lot #3 (Milestone #6).
- Complete Lots #4 & #5, ship and bill them (Milestone #7 & #8).
- Preliminary Design Review #1 August 26-27 at Huntsville.
- Incorporate contract Mod #6 into the program.
- Acquire additional processing fixtures (Milestone #2).
- Investigate high pressure testing of the manifolds at NASA's request.

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_  
----- Main Combustion Chamber

DATE STATUS

- |         |  |
|---------|--|
| 5/6/92  | <ul style="list-style-type: none"><li>• A wax support fixture for the forward manifold chill has been built. This will help prevent the chill from showing through the pattern wall after molding.</li><li>• An assembly error made a molding rerun necessary on the jacket segments. This should not affect the overall schedule.</li></ul> |
| 5/13/92 | <ul style="list-style-type: none"><li>• The planning department has set an estimated completion date of 7/15/92 for Lot #3. This is on an expedited schedule and does not include final destructive evaluations. If all goes well, we should be ready for PDR #1 in early September.</li></ul>   |
| 5/20/92 | <ul style="list-style-type: none"><li>• Lot #3 is in Investing, on schedule.</li><li>• Because of a communication problem, the shell building on Lot #3 has progressed past the point of being able to add cooling passages to the mold. This experiment will have to wait until later in the development cycle.</li></ul>                   |
| 5/27/92 | <ul style="list-style-type: none"><li>• Lot #3 has dewaxed. Estimated cast date is 6/5.</li><li>• The cooling passages were added later than planned and will be used in casting this part.</li></ul>  |

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

DATE STATUS

- 6/3/92
- Cast date will be 6/5 or 6/6 on Lot #3.
  - A minor tool rework is required on the manifold windows. This will be done prior to running any more castings.
  - We are still waiting for a contract modification in order to quote the anticipated additional castings.
- 6/10/92
- Contract mod 4 was received. It added \$26,000 to the current funded allotment. We have still not received the request to add additional parts to the contract.
  - Lot #3 cast over the weekend and is now in gate removal. Visually, it is all there. The pour was very sloppy with a lot of spillage onto the top of the mold. The part and the gating system filled, however. Modifications in casting techniques will be made in the future which will allow the mold to accept the metal more readily.
  - First Inspection Results for Lot #3:  
Finning in the Aft Manifold caused some shell dirt in the casting. The full extent will not be known until it gets to Zyglo. Some bleeding of caustic from the shell removal process is occurring in the necked down area between the ribs. This indicates some shrink that is open to the surface. This will be evaluated at Zyglo.
- 6/17/92
- Lot #3 is being X-Rayed. It will then go to Thermal Etch and on to Zyglo.
  - In order to quote the additional castings and the changes in the current castings, PCC needs an RFQ which shows the contract changes, the required processing for deliverable parts, and the requested delivery dates.

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
6/24/92	<ul style="list-style-type: none"><li>• Lots 4 &amp; 5 are being scheduled. These will be two "best effort" deliverables, trying for a 10/1/92 delivery date. FAB-20 (expedited schedule) delivery has been requested from the PCC planning dept. in order to make the date. These parts will run approximately two weeks apart because of fixture limitations in wax. A contract mod for this change will be forthcoming from NASA.</li><li>• Lot #3 has completed NDT X-Ray and is in Zyglo. Some areas have shrink and others appear to be clean. These will be further examined after cut-up and Chem Mill occurs.</li><li>• We have received a request to ship the pieces of Lot#1 to NASA for their test use. This should occur next week after the data package is put together.</li></ul>
7/1/92	<ul style="list-style-type: none"><li>• Contract Mod. #5 has been received and reviewed. It appears to be no problem.</li><li>• Lot #3 is having windows welded. Results are mixed as this is the first try. Some distortion is present with some techniques. Development will continue.</li><li>• Lot #1 and the data package will ship today. It should be noted that this casting represents the first effort in the AMCC development program and was a product of multiple gating systems. The cut up pieces do not represent the process that will be used to produce usable castings. These pieces should not be used in any way that would represent them as typical of a fully developed part.</li></ul>

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
7/8/92	<ul style="list-style-type: none"><li>• Window welding is complete. The casting went to HIP. The part will then be dimensioned to check weld drop through. some weld defects have been found. The technique will continue to be developed to eliminate these. They will also be evaluated after HIP.</li><li>• The patch thickness will be reviewed with possible changes in thickness required.</li><li>• Lot #4 is in Wax Molding.</li></ul>
7/15/92	<ul style="list-style-type: none"><li>• Lot #3 has been HIPped and will return from Chem Mill today. NDTE will follow.</li><li>• Lot #4 is in Pattern Assembly.</li><li>• Dimensional checks on Lot #3 welded windows indicate some distortion and mismatch. This is being addressed as the welding technique is being further developed. This will be next addressed on an Aft Manifold casting for Rocketdyne (PCC P/N 20004) that is currently in Wax Assembly.</li></ul>
7/22/92	<ul style="list-style-type: none"><li>• The process router needed to run the next 4 shippable parts (Lots 4, 5, 6, 7) is in the computer.</li><li>• Lot #3 is at NDTE. More X-Ray is required. It will then be marked for cut up and micros.</li><li>• After Chem Mill Zyglo evaluation of Lot #3 shows that porosity is present under the casting surface that does not show non-destructively. some of this has been seen on prior castings and some is new. Part of it appears in an area that was affected by metal spillage during the pour.</li><li>• Lot #4 pattern is assembled and is in Gating Assembly. The additional X-Rays on #3 are needed prior to gating #4 in order to get our "best shot" at it.</li><li>• Lot #5 is due out of Wax Molding this week.</li><li>• Lots 6 &amp; 7 for delivery in November will follow.</li></ul>

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

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<u>DATE</u>	<u>STATUS</u>
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7/22/92 (cont'd)• The need for additional processing fixtures (Milestone #2) is being evaluated. It is felt that these can be completed by the October 1992 milestone date.

- 7/28/92
- PDR will be the week of 8/24 at Huntsville.
  - Lot #3 will be invoiced this month. The pieces are at the lab awaiting micros.
  - Lot #5 was delayed in Wax Molding and is behind schedule. This, combined with the amount of processing required (window welding and targeting), puts an end of September ship date in jeopardy. October 15 is more realistic. This is an expedited schedule (FAB-20).





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May 6, 1992

In reply refer to CDR-91-NASA-AMCC

NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting  
Development (AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

We are transmitting data required by contract for your  
information and retention.

Sincerely,



Steve Weber

Program Manager  
Rocket Engine & Space Component Development Engineering  
Program  
Precision Castparts Corp.

cc:	AP25-B_____	1 report & letter
	CN22D_____	3 reports
	AT01_____	1 report
	EM15_____	1 report
	COTR (Code EP62)_____	1 report & letter

NASA Scientific and Technical  
Information Facility\_\_\_\_\_ 2 reports  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090

bjh/7354

30 April 1992

CDR-91-NASA-AMCC

**QUARTERLY STATUS REPORT**

**NUMBER 3**

**ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM**

**CONTRACT NAS8-39027**

**CDRL NO. 8**

**PREPARED BY**



**G.L. HEMAN  
Project Engineer**

**APPROVED BY**



**S.L. WEBER  
Program Manager**

**Rocket Engine & Space Component Development Engineering Team**

**PRECISION CASTPARTS CORP.  
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30 April 1992

CDR-91 NASA-AMCC

## QUARTERLY STATUS REPORT

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## **QUARTERLY STATUS REPORT**

### **INTRODUCTION**

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- \* To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main Combustion Chamber (MCC).
- \* To accomplish this by manufacture of twenty-one (21) developmental castings of which delivery to the government will consist of a minimum of nine (9) castings.
- \* NASA will use these nine (9) castings as engineering and process development units or as development prototype ground-test hardware.

This report describes the status of the program and the work performed during the seventh through ninth months of the contract, for the period of February 1992 through April 1992.

## **WORK PERFORMED**

### **Casting Lot #1**

Investing was completed with no problems. The shell was then dewaxed and a dry run performed in the Mastercaster furnace to ensure that the shell could load and unload properly. A fixture was built to support the shell. The shell was then put into the burnout furnace and brought to temperature, monitored by thermocouples to assure that no large temperature gradients existed in the shell during this process.

The part was cast on February 17 with no major problems. It proceeded through the shell removal and gate removal operations and was ready for Non-Destructive Testing Evaluation (NDTE) on February 25.

Preliminary Zyglo showed very few indications. Two of them were in gate stubs, indicating possible shrink areas. These were verified by X-Ray. The part was then cut up, with portions of it hiped and chem milled and then reinspected.

The shrink indications were cap-welded prior to Hip, but all of the shrink did not hip out, indicating that some was open to the surface. This part, however, was a success as the first iteration in the development process for this casting. The results gained here show a definite direction to pursue in gating the next sample part. Coordinate Measuring Machine dimensional checks were taken in both wax and metal.

### **Casting Lot #2**

This casting is the first deliverable piece of hardware and is being run on a "best effort" basis. As such, it was not an integral part of the development process, but was used by PCC as a tool to learn some additional information about the configuration and some additional casting characteristics of the alloy.

### *Casting Lot #2 cont'd*

It was gated with a minimum of gating at the top and bottom of the part and insulation was used to control solidification. The configuration is such that we were sure that the part would fill, thus satisfying NASA's needs. The cup and downsprue were outside the part envelope, causing some concern about locating the mold in the furnace, but a dry run showed that it fit into the chamber and it cast with no problems.

Visual inspection after shell and gate removal showed stains due to open shrink between the ribs on the outside of the part. This was not unexpected, because of the minimum gating that was used. The ends of the part were X-rayed to determine the extent of the shrink, a coating of lacquer applied (with NASA approval), and the part was shipped to NASA for use as a demonstrator piece. CMM dimensional checks were run in both wax and metal.

### **Casting Lot #3**

This is the second engineering gating sample in the development program, The part was molded and started in pattern assembly when it was discovered that some pattern segments had delaminated from the wax chills. The problem was solved by drilling holes in the chills and reshooting the segments. This caused some delay in assembly, but we should be able to make it up and to lose no time in the schedule. Pattern assembly is continuing.

### **MILESTONES COMPLETED**

Milestone four and five were completed and invoiced for \$152,346 each.

### **PROJECT STATUS**

Lot #3 is slightly behind our accelerated schedule because of molding problems, but we are still looking at a June completion date. Modifications to the program have been discussed with NASA that add some additional deliverable parts and pull in some other milestone dates. Resolution of these changes will be quoted when written requests for changes are received.

### **PLAN FOR THE NEXT THREE MONTHS**

- Design a gating system and process Lot #3 through to completion.
- Invoice for Milestone #6.
- Modify the program per NASA's expected request.
- Start preparing for PDR #1.

# PART STATUS--R.E. & S.C.D. ENGINEERING

Page: 5

Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_

----- Main Combustion Chamber

DATE STATUS

- 2/5/92
- Lot #1 is in Investing. The scheduled cast date is 2/17.
  - Lot #2 is in Pattern Assembly.

- 2/12/92
- Contract Mod 3 has been received. This moves one of NASA's three mockups up to March 1992 delivery. This part is now in Wax and on schedule as Lot #2.
  - Lot #1 is on schedule to pour on 2/17.



# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_  
----- Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
2/19/92	<ul style="list-style-type: none"><li>• Lot #1 has completed shell removal and will be going to Machining for gate removal after a preliminary dimensional check. It is slightly ahead of schedule. Visually, it is a very good looking part.</li><li>• Lot #2 (to be delivered to NASA) is on schedule in Investing. The scheduled casting date is 3/4.</li></ul>
2/26/92	<ul style="list-style-type: none"><li>• Lot #1 is at NDTE. Preliminary FPI has been done with very few indications. Two of them, however, are in gate stubs, which could indicate areas of shrink. X-Ray is needed to confirm this. Shooting is scheduled to start today.</li><li>• Lot #2 is still on schedule with a casting date of 3/4.</li></ul>
3/5/92	<ul style="list-style-type: none"><li>• Lot #1 NDTE is almost complete. X-Ray shooting should complete tonight and be available for review tomorrow.</li><li>• Lot #2 should pour tonight. The shell is at temperature and the part will be next to pour on the Master Caster.</li><li>• Jay Dennis of NASA was here on 3/4 to review Lot #1, but had to leave prior to the pour on Lot #2. He did get to observe the burnout operation, review our quarterly reports prior to submittal, and participated in some very helpful general discussions.</li><li>• It is anticipated that both Lot #1 and #2 will complete this month.</li></ul>
3/11/92	<ul style="list-style-type: none"><li>• Lot #1 is cut up and go to Chem Mill today and will return on 3/18/92.</li><li>• Lot #2 is at Machining for gate removal. It may possibly be shipped by 3/20. Per telecom with Charlie Conelius and Jay Dennis, HIP is not required on this first deliverable part.</li></ul>

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_  
----- Main Combustion Chamber -----

<u>DATE</u>	<u>STATUS</u>
3/20/92	<ul style="list-style-type: none"><li>• Lot #1 has been cut up, hipped, and chem milled. NDTE is complete.</li><li>• Lot #2 shipped by truck. It should arrive at MSFC on 3/30.</li><li>• Lot #3, the second Engineering Sample, will mold the first week of April.</li></ul>
3/25/92	<ul style="list-style-type: none"><li>• Lots #1 &amp; #2 were invoiced.</li><li>• Lot #3 is due out of Molding on 4/3.</li><li>• A new milestone schedule needs to be developed. NASA has requested information (which has been provided) concerning early delivery of demonstrator parts. We will establish new milestones when that issue is settled.</li></ul>
4/1/92	<ul style="list-style-type: none"><li>• Lot #2 arrived at NASA and was well received.</li><li>• Lot #3 is being molded. It will be available during the Casting School.</li></ul>
4/15/92	<ul style="list-style-type: none"><li>• Lot #3 is awaiting assembly. The current schedule calls for this to complete in August. We will attempt to bring it into late June or early July.</li></ul>
4/22/92	<ul style="list-style-type: none"><li>• Need request from NASA to modify schedule to bring in two pieces. This will require a change in the program milestones.</li></ul>

## PART STATUS--R.E. & S.C.D. ENGINEERING

Page: 8

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_  
----- Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
4/29/92	<ul style="list-style-type: none"><li>• Conversations with NASA indicate that they will want three more parts this year, but official notification is probably one month away.</li><li>• A lack of fusion between some pattern chills and the pattern has caused a defect in some manifold segments. This caused a delay in assembly until the segments were rerun. The problem was fixed by drilling holes in the wax chills.</li></ul>



# Precision Castparts Corp.

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March 3, 1992

In reply refer to CDR-91-NASA-AMCC

NASA/MSFC  
Marshall Space Flight Center  
Alabama 35812

Contract: NAS8-39027  
Advanced Main Combustion Chamber Casting Development  
(AMCCCD) Program  
Quarterly Status Report

NASA/MSFC:

We are transmitting data required by contract for your information and retention.

Sincerely,

Steve Weber

Program Manager  
Rocket Engine & Space Component Development Engineering Program  
Precision Castparts Corp.

cc:	AP25-B	1 report & letter
	CN22D	3 reports
	AT01	1 report
	EM15	1 report
	COTR (Code EP62)	1 report & letter

NASA Scientific and Technical Information Facility 800 Elkridge Landing Road Linthicum Heights, MD 21090	2 reports
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bjh/7354

11 November, 1991

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 1

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

CDRL NO. 8

PREPARED BY



G.L. HEMAN  
Project Engineer

APPROVED BY



S.L. WEBER  
Program Manager

Rocket Engine & Space Component Development Engineering Team

PRECISION CASTPARTS CORP.  
Large Structural Business Operation  
4600 S.E. Harney Drive  
Portland, Oregon 97206

11 November, 1991

CDR-91 NASA-AMCC

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) Program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- \* To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main Combustion Chamber (MCC).
- \* To accomplish this by manufacture of twenty-one (21) developmental castings of which delivery to the government will consist of a minimum of nine (9) castings.
- \* NASA will use these nine (9) castings as engineering and process development units or as development prototype ground-test hardware.

This report describes the status of the program and the work performed during the first three (3) months of the contract, for the period of August 1991 through October 1991.

### WORK PERFORMED

The contract award was received at PCC on August 6, 1991. This initiated the process of procuring the Tooling that is required to produce the wax patterns which are used in the first steps of manufacturing the AMCC casting.

Because of the part complexity, it was determined that the tooling would be produced in three groups, each group producing one portion of the wax pattern. Several local tooling vendors were then asked to quote the three tooling packages and the assembly fixture that was required to make the final one-piece, assembled wax pattern. These quotes were to firm-up the prices that were offered earlier in the quoting segment of this program.

The tooling was awarded to three different vendors in order to make the required schedule commitments. Coordination by the PCC Engineering Team and the Tool Procurement Group was done to ensure compatibility when the tooling is received. All tooling will arrive by the end of December and be ready for use in January of 1992.

Special fixturing will be required to process this part throughout the plant. A total of twenty-two (22) different items are being designed and ordered. These are also due to be in-house by the end of December.



### **PROJECT STATUS**

No major problems exist. The program is progressing on schedule.

### **PLAN FOR NEXT THREE MONTHS**

The tooling that will be received in December will go through a tool proving process by our Tool Procurement Department. We will then start manufacturing waxes and processing the first Engineering Sample (Lot #1).

The fixtures will be received and put into use as needed. The Assembly Fixture will be dimensionally checked in Layout.

The Coordinate Measuring Machine (CMM) program will be written and the first wax checked.

Milestone #1 will be completed and invoiced.

# PART STATUS -- R.E. & S.C.D ENGINEERING

Page: 1

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: Main Combustion Chamber  
\_\_\_\_\_  
\_\_\_\_\_

DATE	STATUS																				
8/21/91	<ul style="list-style-type: none"><li>Signed drawings will be sent to us today from Huntsville.</li><li>A design modification will change one of the flanges. This will be ROC'd when it occurs. It will be given to the tool vendor as part of the original package.</li><li>Requested IGES files for sheets 4 &amp; 10 from NASA.</li><li>TWA's have been given to Tool Procurement and vendors are being contacted.</li><li>The award date from NASA was August 6th, but final drawings were not available.</li></ul>																				
8/28/91	<ul style="list-style-type: none"><li>Tool vendors have been selected:</li></ul> <table><tr><th>ITEM</th><th>VENDOR</th><th>DEL'Y DATE</th><th>PROVEN DATE</th></tr><tr><td>Fwd Mfld</td><td>Camano</td><td>12/15/91</td><td>1/6/92</td></tr><tr><td>Ctr Jacket</td><td>Havel</td><td>11/3/91</td><td>11/24/91</td></tr><tr><td>Aft Mfld</td><td>DPW</td><td>12/15/91</td><td>1/6/92</td></tr><tr><td>Ass'y Fixt</td><td>DPW</td><td>11/3/91</td><td>12/15/91</td></tr></table> <p>The proven date for the assembly fixture is for completion of layout. The total job will not be proven until all patterns fit in the fixture.</p> <ul style="list-style-type: none"><li>We have signed prints as a result of NASA's visit today. Changes are anticipated, and will be ROC'd. The issue of 18 or 24 ribs is still not settled.</li><li>The SOW is still not final. A revised SOW will be generated. No date was established.</li><li>Another visit is expected on September 16 &amp; 17.</li></ul>	ITEM	VENDOR	DEL'Y DATE	PROVEN DATE	Fwd Mfld	Camano	12/15/91	1/6/92	Ctr Jacket	Havel	11/3/91	11/24/91	Aft Mfld	DPW	12/15/91	1/6/92	Ass'y Fixt	DPW	11/3/91	12/15/91
ITEM	VENDOR	DEL'Y DATE	PROVEN DATE																		
Fwd Mfld	Camano	12/15/91	1/6/92																		
Ctr Jacket	Havel	11/3/91	11/24/91																		
Aft Mfld	DPW	12/15/91	1/6/92																		
Ass'y Fixt	DPW	11/3/91	12/15/91																		
9/4/91	<ul style="list-style-type: none"><li>IGES files are expected by 9/13.</li><li>The Center Jacket Tool has not been officially placed by PCC Purchasing. This is being worked by Bob Bodyfelt, Tool Procurement Manager.</li></ul>																				

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_

----- Main Combustion Chamber -----

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## DATE

## STATUS

- | DATE     | STATUS  |
|----------|---|
| 9/11/91  | <ul style="list-style-type: none"><li>• Tooling for the jacket tool has been placed with Havel.</li><li>• John Davis will visit DPW tomorrow to look at the Aft Manifold and the Assembly Fixture Drawings.</li><li>• A visit to NASA for a post award meeting will be made on Sept 16 &amp; 17 by Myrna Nutting, Steve Weber, John Davis, Jeff Miller, and Bruce Haphey.</li></ul> |
| 9/18/91  | <ul style="list-style-type: none"><li>• We have been asked to quote 1 or 2 pieces using the current tooling, modified to make the NASA configuration.</li><li>• PCC's concerns with the S.O.W. and the casting specification were satisfied during the visit to NASA, which went very well.</li></ul>   |
| 9/25/91  | <ul style="list-style-type: none"><li>• The quote for the additional two pieces from existing tooling should complete today.</li></ul>  |
| 10/2/91  | <ul style="list-style-type: none"><li>• We are awaiting a P.O for the two additional castings and a release to use the existing tooling.</li></ul>  |
| 10/9/91  | <ul style="list-style-type: none"><li>• No word yet on a P.O. for additional castings.</li><li>• Design and procurement of processing fixtures is beginning.</li></ul>  |
| 10/16/91 | <ul style="list-style-type: none"><li>• Camano Tool has requested a two-week extension on the Forward Manifold Tool as a result of receiving the DER for Rev. B. This will be worked to see if the effect can be minimized.</li></ul>   |

## PART STATUS--R.E. & S.C.D. ENGINEERING

Page: 3

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_  
----- Main Combustion Chamber-----

<u>DATE</u>	<u>STATUS</u>
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10/30/91

- The two week tool extension on the Forward Manifold should not affect our schedule as we can use preliminary tooling shot waxes for mockup #1. This will take some juggling by Wax Molding, but should be obtainable.
- Discussions between John Davis and Neill Myers have resulted in a Rev "C" drawing which we should see soon. It is expected that the changes are for clarification and will have no effect on tool construction.
- Memos describing tool marking instructions will be distributed shortly. We should have the tooling marked by the vendors prior to receiving it if possible.

02 February 1992

CDR-91-NASA-AMCC

QUARTERLY STATUS REPORT

NUMBER 2

ADVANCED MAIN COMBUSTION CHAMBER  
CASTING DEVELOPMENT (AMCCCD) PROGRAM

CONTRACT NAS8-39027

CDRL NO. 8

PREPARED BY



G.L. HEMAN  
Project Engineer

APPROVED BY



S.L. WEBER  
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Rocket Engine & Space Component Development Engineering Team

PRECISION CASTPARTS CORP.  
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02 February 1992

CDR-91 NASA-AMCC

## QUARTERLY STATUS REPORT

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## QUARTERLY STATUS REPORT

### INTRODUCTION

The Advanced Main Combustion Chamber Casting Development (AMCCCD) program (Contract NAS8-39027) has a 43 month period of performance from August 1991 to February 1995.

Objectives of the Program are:

- \* To demonstrate that a precision investment casting process will produce a structural jacket and cooling manifold design which is more reliable, producible, and cost effective than the existing wrought, machined, and heavily welded design used for the current SSME Main Combustion Chamber (MCC).
- \* To accomplish this by manufacture of twenty-one (21) developmental castings of which delivery to the government will consist of a minimum of nine (9) castings.
- \* NASA will use these nine (9) castings as engineering and process development units or as development prototype ground-test hardware.

This report describes the status of the program and the work performed during the fourth through sixth months of the contract, for the period of November 1991 through January 1992.

## **WORK PERFORMED**

Pattern tooling was built and received in-house. Visits to the tooling vendors by PCC Tool Procurement and Engineering personnel during tool construction assured a minimum of problems and on-time delivery. The tool proving process took place whereby the tools were tested in the wax injection machines and produced their first patterns. No major problems occurred and the first wax pattern was tacked together from these tooling shot patterns. This wax was used to program the CMM.

Two pieces of the Aft Manifold Tool went back to the vendor for slight adjustments, but did not affect the schedule. The tool proving operation was complete upon their return. The Assembly Fixture was checked in Layout and found to be acceptable.

Word from NASA was received saying that they wanted their first deliverable part ASAP. The wax for this part will be shot as Lot #2. Lot #1 wax was shot and assembled. The pattern went together very well with a minimum of problems despite being assembled with 25 separate wax pattern pieces. The wax pattern storage fixtures and the assembly fixtures all worked and were instrumental in making this a smooth operation. The pattern was then checked dimensionally on the CMM.

Casting was designed by the part engineer and manufactured and assembled by the engineering assembler in the Wax Assembly department. The assembly was then framed in preparation for the investing process.



### PROJECT STATUS

No major problems exist. The program is progressing on schedule.

### PLAN FOR NEXT THREE MONTHS

Lot #1 will complete processing and engineering evaluation.

Lot #2 (NASAs first deliverable mock-up) will complete processing through HIP and ship.

Both of the above lots will be invoiced. These will be Milestones 4 and 5, per Contract Mod. #3.

The second engineering evaluation part (Lot #3) will be scheduled and be molded in wax.

# PART STATUS--R.E. & S.C.D. ENGINEERING

Page: 3

Customer: NASA PCC P/N: 20013  
Customer P/N: 96M66441 Program: SSME  
P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_  
\_\_\_\_\_ Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
10/30/91	<ul style="list-style-type: none"><li>• The two week tool extension on the Forward Manifold should not affect our schedule as we can use preliminary tooling shot waxes for mockup #1. This will take some juggling by Wax Molding, but should be obtainable.</li><li>• Discussions between John Davis and Neill Myers have resulted in a Rev "C" drawing which we should see soon. It is expected that the changes are for clarification and will have no effect on tool construction.</li><li>• Memos describing tool marking instructions will be distributed shortly. We should have the tooling marked by the vendors prior to receiving it if possible.</li></ul>
11/6/91	<ul style="list-style-type: none"><li>• It is anticipated that the tooling and fixtures that are included in Milestone #1 will be completed in December.</li></ul>
11/12/91	<ul style="list-style-type: none"><li>• Rev. C drawings were received today and will be reviewed.</li></ul>
11/20/91	<ul style="list-style-type: none"><li>• The Report of Change (ROC) is being prepared for our review of the "C" revision print.</li><li>• Design and construction of all fixtures is underway.</li></ul>
11/27/91	<ul style="list-style-type: none"><li>• There is an error on the blueprint. The tooling already includes it. The surface of the ears will not be coplanar, as they should be. The intent is to get the tooling in-house, run the engineering sample casting, and then repair the tools at NASA's direction. The tooling vendor will provide quotes for two (2) options.</li></ul>

# PART STATUS--R.E. & S.C.D. ENGINEERING

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Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_

----- Main Combustion Chamber -----

<u>DATE</u>	<u>STATUS</u>
12/4/91	<ul style="list-style-type: none"><li>• NASA to review first wax pattern and evaluate impact. Decision to be made at that time if tool rework will be required.</li></ul>
12/11/91	<ul style="list-style-type: none"><li>• The Forward Manifold tooling is in-house and in Tool Proving. The Jacket tool is due to be shipped from the vendor on 12/13. The Aft Manifold tooling is due on 12/16.</li><li>• Wax fixtures are due 12/16.</li><li>• We are expecting to have a wax to gate by January 15 depending upon tooling arrivals and Wax Molding availability.</li><li>• We are awaiting official word from NASA to move their first deliverable part up in the schedule. We are expecting to input it right behind the Lot #1 Engineering Sample.</li><li>• Engineering review of B/P Rev. C is complete. Tool Rework will be required and is being quoted.</li></ul>
12./18/91	<ul style="list-style-type: none"><li>• Lot #1 of the Forward Manifold will be shot the week of Dec. 30. The others will be completed based upon tool availability.</li></ul>
1/8/92	<ul style="list-style-type: none"><li>• All pattern tooling has arrived and been shot. The first tooling shot pattern has been tacked together in the assembly fixture. It went together very well considering that the tools came from three different vendors. Two pieces of the Aft Manifold went back to the vendor for minor work and should be back on Friday. Molding for Engineering Sample #1 should begin next week. The Tooling Shot Pattern will be used for CMM Programming.</li><li>• The pattern for the first part to be delivered to NASA can then follow in 2-3 weeks depending upon the availability of the fixturing from Lot #1.</li></ul>

# PART STATUS--R.E. & S.C.D. ENGINEERING

Page: 5

Customer: NASA PCC P/N: 20013

Customer P/N: 96M66441 Program: SSME

P.O. Nos: \_\_\_\_\_ Description: \_\_\_\_\_

----- Main Combustion Chamber

<u>DATE</u>	<u>STATUS</u>
1/15/92	<ul style="list-style-type: none"><li>• Wax Molding is progressing.</li><li>• Discussion concerning addition of these parts (Lots #1 &amp; #2) to the FAB 20 list for March completion is going on.</li><li>• Neill Myers and Jay Dennis from NASA will visit on Jan. 21 &amp; 22 to review our progress with the first wax.</li></ul>
1/24/92	<ul style="list-style-type: none"><li>• Lot #1 wax was assembled while Neill &amp; Jay were here and is now in CMM for dimensional inspection.</li><li>• The package (tool list &amp; pictures) has been completed and the billing authorization sent to sales for Milestone #1. The amount is \$583,699.00. Jay Dennis indicated that the package would be acceptable to NASA for billing purposes. Pam Wright did a super job on this as the package covers 99 items.</li><li>• The plant has committed to completing Lot #1 and possibly Lot #2 by March 27.</li></ul>
1/29/92	<ul style="list-style-type: none"><li>• Lot #1 will complete Assembly today and start Investing tomorrow, on schedule.</li><li>• Lot #2 has not yet been molded.</li></ul>

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
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4. TITLE AND SUBTITLE quarterly status report number 4 Advanced main Combustion Chamber Casting			5. FUNDING NUMBERS Contract NAS8-39027	
6. AUTHOR(S) G.L. Heman S.L. Weber			8. PERFORMING ORGANIZATION REPORT NUMBER CDR-91-NASA-AMCC	
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